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VOL. XLV

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THE HAWAIIAN PLANTERS' RECORD

VOL. XLV

ORGAN OF THE EXPERIMENT STATION OF THE HAWAIIAN SUGAR PLANTERS' ASSOCIATION

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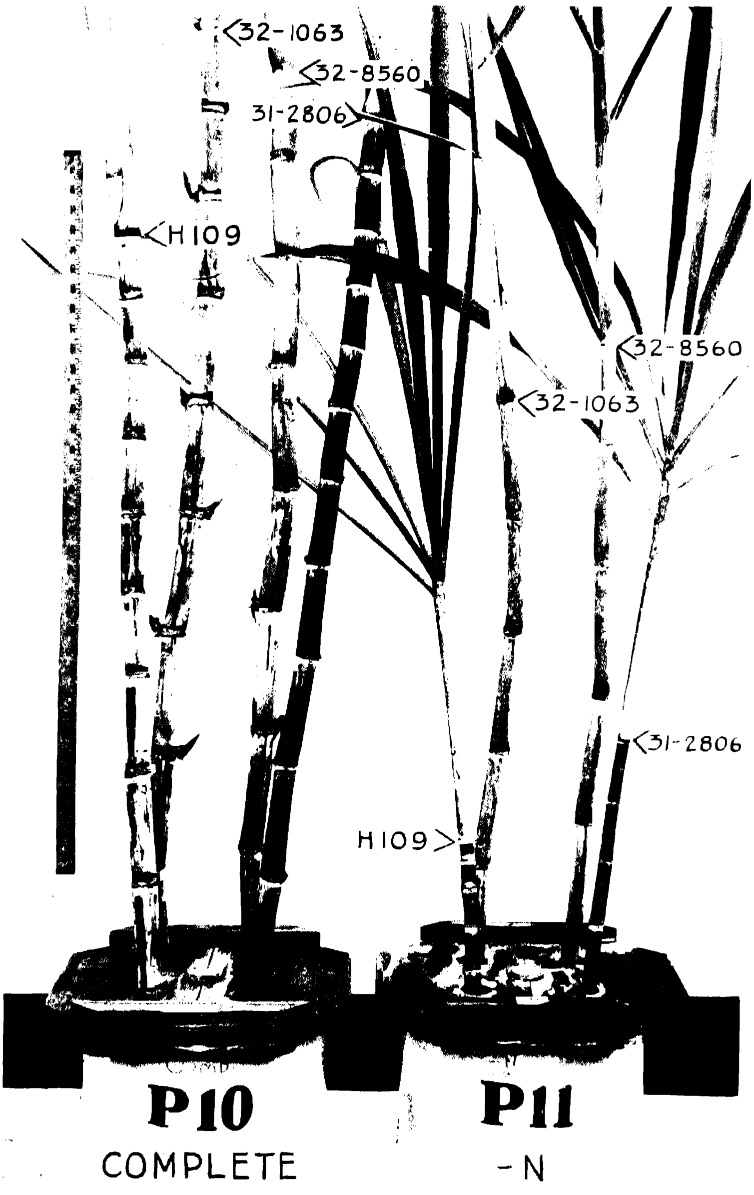


Sugar cane varieties manifest differences in growth, yields, and tolerance to nutrient deficiencies.

The Laysan albatross or white gooney, one of the most interesting inhabitants of Midway Islands.

FOURTH QUARTER

ffect of climate on 32–8560 cane grown on two different soils. Left to right: (1) on akiki soil at Makiki; (2) on Makiki soil at Manoa; (3) on Manoa soil at Makiki; (4) on Manoa soil at Manoa.

Errata

THE HAWAIIAN PLANTERS' RECORD
VOL. XLIV, NO. 4, 1940

Lines at bottom of Table II, page 238, and Table III, page 239, reading:

"Difference required for odds of 19 to 1"

Should read:

"Difference required for odds of 99 to 1"

THE HAWAIIAN PLANTERS' RECORD

Vol. XLV FIRST QUARTER 1941 No. 1

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Sugar Proceeds:

The factors contributing to, and determining the price structure of refined sugar in the retail markets of the United States are discussed. The difficulties attending the marketing of Hawaii's large crops of raw sugar are pointed out and the conclusion reached that the prevailing policy of selling as a unit, rather than in competition, must be continued if our industry is to survive.

Canton Island:

A brief description is given of this south-Pacific station on the P. A. A. route to New Zealand, together with some information as to the plant and animal life occurring there. A knowledge of Canton's insect fauna is particularly useful in connection with the Clipper plant quarantine service maintained by the H. S. P. A.

Observations on Insect Pests in Samoa Which Are Not Yet Known to Occur in Hawaii:

This illustrated paper gives an account of seventy species of injurious insects in Samoa which are not known in Hawaii; they are listed according to their food plants. Quite a number of them would prove to be serious pests if they should become established in Hawaii, and continuous vigilance should be maintained to prevent this.

Soil Fertility as Affected by Soil Nitrogen:

The use of nitrogen fertilizer in a way that will insure its maximum economic efficiency continues to be one of our most vital problems. Continually changing soil conditions, which are brought about when nitrogen fertilizers are applied and when

organic materials are added, affect the activities of the soil organisms which are active in the decomposition of this organic matter, with the result that the supplies of nitrogen available for crop growth can fluctuate sharply within small localized areas. Data are offered in this paper which contribute to a better understanding of the part that may be played by the soil organisms as they withdraw or release soil nitrogen and affect soil fertility.

Sugar Proceeds*

By R. A. Cooke

For some decades Hawaiian sugar plantations have enjoyed an enviable reputation for high efficiency—as high as that of any other group of agricultural enterprises and perhaps even higher. Early data with respect to acre-month yields or man-days performance which would be used today as the prime measures of efficiency were not kept. Still we do know that the Hawaiian crop for the year 1901 was 360,038 tons of sugar and that the number of plantation employees at that time was 39,587. Thirty-nine years ago, therefore, about 9.09 tons of sugar were produced for each employee. The corresponding ratios by decades were 12.07 tons of sugar per employee for the year 1910, 12.57 tons of sugar for 1920, and 16.47 tons of sugar for 1930. This year, according to present estimates, about 22.45 tons of raw sugar will be produced by our plantations for each worker on the pay rolls.

This, to be sure, is quite a rough measure of efficiency and, as you well know, many other factors should be included. It is, however, sufficiently accurate to establish beyond doubt a record of remarkable achievement by you and your predecessors—a record of which Hawaii and other parts of the United States are justly proud. Still, efficiency in itself is merely a means toward an end. That end is the creation of additional capital which is directly beneficial to the owners of the companies, and with no uncertainty to all others. The reverse is likewise true. If sugar is produced at a loss rather than at a profit, not only are the stockholders made unhappy but sooner or later, because of this probable depletion of the resources, all others are to some degree adversely affected.

Whether our results are profitable or otherwise depends upon two factors only—the cost of landing raw sugar at market and the price received. For annual results each of these is of equal importance. Your work has been entirely concerned with cost and almost entirely with net cost, namely, the cost of production. Unquestionably, under the law of the survival of the fittest (which law by discrimination against Hawaii has been tampered with by our Congress with its quotas and by the Sugar Division with its wage determinations), low cost at market is of vital importance to our industry. But also, without question, under the law of diminishing returns which I believe still remains intact, the room for further decreased cost is very limited. This is partially true because, as distinguished from other domestic areas, our cooperative scientific efforts have been exerted for well over half a century. As a matter of fact—with taxes, freight rates, and prices of materials all beyond our control and all on the increase, with production curtailed by quotas and minimum wages fixed by law and regulations—about the only opportunity remaining for further progress is the maintenance of present production with the use of less material and labor.

You know far more than I regarding all items governing the first factor deter-

*Presented at the Third Annual Meeting of the Hawaiian Sugar Technologists, November 25, 1940.

mining the success of our industry—the cost of landing our sugar at market. With respect to the second factor—the price received for our sugar—we who are concerned with production costs have been inclined to allow nature to pursue its own sweet course. Perhaps because you can do nothing about it, the price received has been accepted the same as the weather, except that the grumblings have been somewhat more audible and justly so. Therefore, rather than tackle you on your own home field, I am going to take you into a field which may be strange to you and tell you something about this second factor—the price we receive for our sugar. I do not mean the broad economics of sugar, but rather the general make-up of the price structure, marketing practices of the refiners, and finally the problems which confront us in endeavoring to obtain maximum net proceeds for our sugar. This field has wide expanse and much of it covered with a heavy growth of underbrush. A few high spots are set forth in official statistical tables but there are no real maps since literature on this subject seems woefully lacking. Hence if your guide, who finds himself quite out of his own bailiwick and has had to rely on oral directions given in almost a foreign language, leads you into a blind alley or wanders off the trail, you should not hold him to account.

In giving you some ideas of the price structure of sugar, I have decided to go backwards. We will start with the final price—the retail price paid by the housewife. After she obtains her sugar there is no further price change. The housewife buys her sugar in pounds and probably for this reason all sugar quotations are expressed in cents per pound. The unit used by the refineries and beet processors is usually the bag—a 100-pound bag. Occasionally they too use the pound as their unit and with their detailed cost statistics one encounters figures with decimal places long enough to have a perspective. Our unit is the short ton and since you and I are accustomed to thinking of costs and receipts at so much per ton, I will convert all data to a tonnage basis.

The official retail price of refined cane sugar is today about $104 a ton. This, however, is merely an average compiled by the government from seventy-odd cities throughout the United States. And I will add right now that implicit faith in averages has possibly caused more ruination than alcohol. A friend of mine in New York purchased on the same day two identical five-pound packages of refined sugar from two stores each within a block from his home. For one he paid 25 cents and at the other store he was charged 30 cents. The difference in these retail prices was equal to $20 a ton. Now isn't that disgusting? Here in Hawaii about $100 must be invested for the annual production of a ton of sugar and a difference of $20 a ton means the difference between a profit of 10 per cent or an equivalent serious loss. We toil and sweat to save 20 cents a ton while retail stores are throwing away $20. If, as happened a year ago, the price for our raws advances $10 a ton, there is a great hue and cry over the poor housewife, yet that poor housewife is too lazy to walk or drive in her auto two blocks to save twice that amount. Although a difference of a cent per pound or $20 a ton may be exceptional, half of that amount of difference between stores in the same community for the same grade of sugar is common. Here in Honolulu we have found a spread of $14 a ton. The reason for this wide spread is not so much because certain stores are able to purchase their supplies of sugar at a lower cost or because others are exacting exorbitant profits, but primarily because some grocers use sugar as a leader.

Below the retailers' prices there are, of course, the prices charged by the wholesalers and jobbers. So far as I know, no record of these prices officially or otherwise is kept or published. Going down the line we next have the prices of the refineries. Their daily average of public quotations for granulated sugar is $14 to $20 less than the average price of retailers. Actually the spread between retailers' and refiners' prices is much wider than that indicated by daily averages because the refiners, on account of handouts to their buyers, fall way short when it comes to their receiving the daily average of their quotations. The difference, amounting to perhaps $25 a ton, between the retailers' price and what the refiners receive seems to be shrouded in mystery. In it, of course, are included operating costs and profits of retailers, wholesalers, brokers, and other cuts, but its breakdown defies analysis.

The underdog of this price structure is of course the raw cane sugar producer. The New York market price for raws has lately been about $32 a ton less than the base price for refined. This difference, which fluctuates to quite an extent, is called the "refiners' margin." After deducting the processing tax and the loss entailed by certain sales policies, the actual refiners' margin is whittled down to say $18 a ton. Refiners have been called "nothing but Chinese laundrymen" but this is hardly fair. Only a half of the margin is needed for refining including raws lost in the process—the balance being required by the refiner for selling, distribution and overhead costs. If anything remains, which is seldom these days, the refiner gratefully records it as profit. We receive for our raw sugars $3.50 to $4.50 a ton less than the New York market price for raws, which makes us bottommost in the pile of underdogs.

But just what determines the price of sugar? I mean ignoring the effects of tariffs, quota restrictions and distribution and refining costs; why it is that the average retail price is around $100 a ton rather than twice or half that amount? We talk glibly of the law of supply and demand but just how does it operate? According to this law the price of a product in a given locality is the price at which a willing seller will sell in such locality and at which a willing buyer will buy. That sounds simple enough, but is it? The ultimate buyer is the consumer and he should not be at all unwilling if he had to pay say $120 a ton since that was the five-year average price he paid before the first World War. He purchases from the retailer, who apparently is a very willing seller as long as he makes a reasonable profit or even keeps to a slight loss. But the retailer is also a buyer since he must purchase his sugar from wholesalers or jobbers who in turn are buyers as well as sellers since they must obtain their supplies either from the cane sugar refineries, the beet companies or from plantations which refine their own sugar. But cane sugar refineries themselves are buyers as well as sellers since their willingness to sell at a certain price depends upon the price which they must pay for raws. And, finally, we have the poor producers of raw cane sugar, who are not at all happy over selling their product at what has been termed tragically low prices, but since they can do little or nothing about it, I suppose, with our fingers crossed, we will have to class them as willing.

Someone along this house that Jack built is responsible for the price of sugar, but who? Is it a question of whether the hen laid the first egg or the egg hatched the first chick? The answer probably is that the housewife, retailer, wholesaler, refiner, and raw producer all exert some influence, but in each case the character

and extent of it is constantly subject to the whims of that elusive autocrat—general conditions. For example, in the early years of the first World War, when the sugar supplies from central Europe were cut off, there was a definite shortage of raw sugar and the sellers of raws were probably the prime factor in determining the price of sugar. Last year, on the declaration of war, consumers became panicky and demanded more sugar for prompt delivery than was immediately available. Because of their demand retailers increased their prices to eight and ten cents a pound and even higher. I heard of one willing buyer who paid nineteen cents a pound—$380 a ton! All producers were not only willing but anxious sellers at only a fraction of these prices but their sugars were not available in the shape of refined at the right places at the right time. Wholesale prices of refined and also raw prices advanced because of the demand of consumers. During 1918 and 1919. because of the shortage of sugar supplies, the government fixed the prices for both raws and refined, but took no action with respect to retail prices. Under those conditions the distributors—retailers, wholesalers, and jobbers—were the principal factors governing retail prices. Usually the difference between retail and refiners' prices is around $20 a ton, but during those two years this difference averaged $80 a ton. The distributors took advantage of the situation and cashed in.

But, except under unusual circumstances, the standard cane sugar refineries exert by far the most dominant influence on the whole chain of sugar prices. Being the first in the field, handling as they do about two thirds of the sugar sold and being practically the sole purchasers of all raw sugars, it is natural that they should be the bellwethers of the sugar market. But even their influence is decidedly restricted by the sellers of raws and many other forces beyond their control. As a result of the refiners' influence on price levels, there is a more or less fixed relationship between prices of all sugars throughout the United States. In other words, the principal standard to which other prices are related is the cane sugar refiners' wholesale price for granulated refined sugar. This is the big umbrella and while others than the refiners do lift or lower and at times tilt this umbrella, its shape is kept fairly constant.

The surface of this price umbrella is not, speaking geometrically, a plane surface since it not only has length and breadth but also thickness. I have already pointed out that this thickness—the difference between the retailers' price on the top and the raw price on the bottom—amounts to about $50 a ton. The refiners' granulated price is located about in the middle. Above the refiners' price and directly related to it are the wholesalers' and jobbers' prices and also all the refiners' prices for specialties—cubes, powdered sugar, etc. Below this price and almost as directly related to it are the beet sugar prices and prices of sugars refined by plantations. The lowest stratum consists of the raw prices. These can fluctuate to quite an extent without disturbing the other various price strata, but if there is a change in the refiners' granulated price, all other prices, except raws, move almost in unison.

Besides not being a plane surface, the refiners' price umbrella is not by any manner of means a flat surface. This is because the price structure is built upon the basing point system. Let me explain what I mean. Each cane sugar refiner adds to his price, so far as he is able to do so, the cost of transporting his sugar from his refinery to the locality in which his sugar is to be sold. The price basis, therefore, in each city of the United States is the lowest price at which sugar can

theoretically be delivered in that city by a cane sugar refinery. For instance, the lowest freight rate from any cane sugar refinery to Chicago is at present $6.40 a ton. The price basis for cane sugar in Chicago is therefore $6.40 over the wholesale price of refined. If because of its locality it costs a refinery $10.40 to transport sugar to Chicago, that refinery must absorb an extra cost of $4.00 a ton on sugar marketed there. This is called "freight absorption." On the other hand, if it costs a beet processor only $2.40 a ton to transport his sugar to Chicago, he has a price advantage of $4.00 a ton. This is called a "freight pickup." Beet processors, offshore refiners and occasionally small mainland refineries are able to gain by freight pickups. The standard cane refineries cannot do so directly since they are the ones who were forced to establish and who must now maintain the price structure.

There are about half a dozen small refining plants in New York and Louisiana which produce but a few grades and packages and which generally sell below the established price basis. The so-called "standard" cane sugar refineries are eighteen in number, each with a wide distribution, overlapping and coming into competition one with the other. Their prices must be kept in line. If the prices of any one of them are over the general level, that refinery, because of competition, will be unable to sell, while if they quote prices below those of their competitors, the others must meet the reduction or they in turn will lose business. All eighteen are located where their supplies of raw sugars can be most economically obtained and since most of the raw sugar is shipped from Hawaii, Puerto Rico, the Philippines, and Cuba, they are built on ocean harbors where satisfactory dockage facilities are available. Each of these refineries is a basing point. Often because of competition of whites from Cuba and Puerto Rico, other ports along the Atlantic seaboard where there are no refineries are established as basing points.

Therefore, the shape of the sugar price umbrella resembles quite closely the general contour of continental United States. The lowest points are along the coasts, with slight humps between ports, a dip in the Gulf because of cheaper raw sugar freights from Cuba and Puerto Rico, a slight rise in San Francisco and again humps in Los Angeles and the ports of the Northwest. As we leave the coast and go inland the price level rises—somewhat more abruptly in the West than in the East and rather gradually up the valley of the Mississippi because of the relatively lower costs of river transportation.

Because of the importance of the sugar cane refineries to sugar prices, and also since our plantations own and operate the California and Hawaiian Sugar Refining Corporation, known as C. and H., I am going to discuss some of their marketing practices and problems. Before doing so, however, I am going to say a few more words on the discount accepted on beet sugars and offshore refined sugar. These sugars always sell from two to four dollars a ton and sometimes much more below the price obtained by the cane sugar refineries even though there may be no difference whatsoever in quality. Why is this? It certainly is not because of any sympathy for the consumer. The cane refineries have the chance of taking reductions out of the hide of the raw producers but with beets and offshores, discounts come out of their own pockets. The reason is partly psychological and partly practical. Formerly, beet sugar, and this still applies more or less to offshores, was inferior in quality and for this reason could not command prices equal to refined cane.

Although no one but an expert can now detect any difference between refined cane sugar and good beet sugar, the reputation of being inferior persists. The ballasting of the Malolo may be perfected, its name may be changed, but the Matsonia is still erroneously considered by many a roller. The practical reason for the discount on beets, called the beet differential, is that wholesalers and jobbers as a rule desire their sugars in various grades and packages. Beets cannot supply many of these. C. and H., for example, regularly quotes 34 different grades of refined sugar packed in 135 different forms and sizes of containers. Plantations and small refineries are handicapped not only by being unable to supply assortments but also because at times they cannot provide the quantity desired.

Just as the cane refineries' basing point system and beet and offshore whites differentials have developed and are now accepted as "customs of the trade," other marketing practices have evolved and have been in use so long that they are now taken for granted. Consider, for example, the 2 per cent cash discount allowed by both beet and cane refineries for payment within ten days after delivery. Two per cent for ten days is equivalent to an annual interest rate of 73 per cent. If this cash discount could be reduced to one per cent, which should be ample inducement for prompt payment with money as cheap as it is, the theoretical saving would be almost $1.00 a ton.

But of much greater consequence is the practice of giving customers a day's notice of any advance in the price and permitting them to book orders at the old price. Mind you, they do not buy but merely contract to buy. And the contract is entirely one-sided. If the buyer wants the sugar he demands delivery and makes payment at the old price less 2 per cent within ten days. But if the buyer finds that he cannot resell at a profit, the seller is left holding the bag or bags. If the price declines, his contract is cancelled and he can wait until another notice of advance and book again. Bookings used to be limited to customers' requirements from 7 to 30 days but recently contracts extending for many months have been given. The result of this practice of advance price announcements is that about four-fifths of the sugar sales of the refiners occur between the time of announcements and the time they become effective. During a year there may be less than a dozen of such announcements. It therefore follows that except for a few day-by-day sales, the refiner never receives any peak quotation.

The practice of giving an advance notice of an increase in price seems to be an overgenerous concession but cannot be avoided. Bear in mind that sugar is a uniform product and that every part of the United States is or can be supplied by many large sellers, both beet and cane refiners. Each of these has, after many years of effort, built up its coterie of customers and a customer lost is not easily regained. An advance in price must be made by individual initiative since any agreement on the part of the sellers would be illegal. If one seller, because of his judgment of marketing conditions, advanced his price without notice, he would hand over his customers to his competitors. Unless bookings were permitted on a notice of advance, there would not be much chance for increased prices. But allowing customers to book their requirements for many weeks and even months, is nothing more nor less than "cutthroat" competition.

The price guarantee to arrival is another costly marketing practice which originated logically enough but which has since, through competition, been abused. This

means that if a customer purchases sugar to be delivered in so many days and before delivery the price goes down, he is billed at the lower price. The two Pacific coast refineries are responsible for originating this practice. Today cane and beet refiners, because of competition, maintain what they call "warehouse stocks" in the various cities and towns where their sugars are distributed. The cost of warehousing, insurance, etc., is borne by them. Several years ago it was the practice of the cane refiners to distribute nearly all of their sugar by direct shipment to the buyers in carload quantities. At that time, however, the Pacific coast refineries found that they could not meet the competition of the Gulf and Atlantic coast refineries with sales throughout the central parts of the United States because of the extra time required for delivery. A jobber or wholesaler could purchase from the Gulf, receive delivery within a few days and resell to his retailer customers immediately. If, however, he purchased from a Pacific coast refiner and the price declined before the sugar reached him, he was out of luck. Hence, since the Pacific coast refiners had to market in this territory, the only method by which they could overcome their disadvantage was by guaranteeing their sales against declines. And just as one rotten apple sooner or later ruins the whole barrel, this practice has spread and infected the whole market.

It is primarily because of these two practices, bookings on advance notices and guarantees against declines, that the average price received by the refineries is considerably less than the daily average of refined quotations. I have not the figures for 1939, but for 1937 the daily average of quotations was $94.88 a ton, while the average price received by the standard cane sugar refineries was only $89.16 a ton—a loss of $5.72 a ton. In 1938 this loss was $3.44 a ton. Because of these practices a fluctuating market, either up or down, works out as a rule to the disadvantage of the refiner. If the price advances, his customers book at the old price and to supply them, he must buy raws at the advanced price. When it declines, he is usually stocked with sugar refined from raws purchased on a higher basis.

Other general practices, all for the buyer and against the interests of the seller, such as the four-payment plan, differential routes, arbitrary prepays, etc., might be explained but are scarcely important enough to dwell on here. When it comes to demoralizing marketing conditions these are "small change" compared to what has been termed the secret concession system. This was the practice by individual refiners, both beet and cane, of making sales to individual customers or groups of customers on secret terms or prices more favorable than those offered to the general trade, instead of selling to all on openly announced terms and prices. Along about the middle twenties, marketing conditions became particularly bad, and at that time secret concessions were given consisting of such practices as simple price rebates; payments to customers of brokerage fees; storage charges and advertising costs which were never incurred; the substitution of higher priced goods than those actually billed; delayed billing; free trucking; allowing buyers to increase bookings after a price advance was in effect; plus many others. In 1928 the cane refiners attempted to remedy this situation through the formation of the Sugar Institute, under which organization a code of ethics together with rules and regulations whereby discriminatory practices would be discontinued were mutually adopted. Unfortunately, although the matter was first taken up in Washington, this organization was declared technically illegal and today the refiners are under an injunction pre-

venting them from regulating under concerted action the sales ethics of their business. The concession system without necessarily discriminatory sales has again crept into the marketing of sugar, perhaps in an even more subtle form than ever before.

Although the marketing of sugar is at present in a decidedly unhealthy state, the opposite was the case fifteen years ago. The present and recent status of the market has been brought about by a change in conditions. During and after the first World War the cane sugar refiners sold much sugar to Europe. In 1922 they processed and re-exported 882,000 tons. This business has all but disappeared. Offshore whites have made a dent in their business to the tune of about half a million tons. During this same fifteen-year period beets have expanded by six to seven hundred thousand tons. To be sure, increased consumption has offset to some extent these losses but the net result has been a decrease in the domestic refining business by about 20 per cent. This explains why the cane refineries have made such strenuous efforts to obtain legal restrictions on offshore whites. These sugars not only take business from the refiners but since they are sold at a discount in the cane refiners' natural territory they have a very demoralizing effect upon the market.

On account of their loss in business the cane refineries at present are operated at about 60 per cent of their capacity. The cost curve of refining dips sharply with an increased melt. The out-of-pocket cost of refining additional sugar is very low—not much more than the cost of the containers. It is natural, therefore, that both the administrative and plant departments of the refineries should exert heavy pressure on their sales departments to market additional sugars.

The sale of beet sugars has contributed its share to the confusion. Because of the expansion of beets their companies have been compelled to blast their way into already overcrowded markets. The quota system has aggravated the situation. Hawaiian quotas can be filled by merely shipping raw sugar to the mainland but a beet company in order to fill its allotment must actually sell its sugar. Otherwise its rights are lost, at least so long as the present quota system prevails.

Another factor having a bad influence on marketing conditions has emanated from the brokerage system. Almost all refined sugar is sold through brokers who are quite but not entirely independent of the refiners. As compensation, brokers usually receive about 5 cents a bag or a dollar a ton. Some years ago an Eastern refiner attempted to sell his sugar direct without the use of brokers but this proved a dismal failure. It is now generally accepted that the brokerage system is the most economical method of securing sales. Since the brokers' earnings depend entirely upon the quantity sold, regardless of the price, it is natural that, in their efforts to sell, they at times overlook the interest of the refiner, who actually pays them their commission.

With symptoms such as these, is it any wonder that the patient is pretty sick? Refiner *A*, be he beet or cane, finds through his broker that he can sell a few thousand bags in the territory of refiners *B*, *C*, and *D* perhaps five hundred miles from his home base. Figured as additional business this is profitable, but does it help him? Not at all, since refiners *B*, *C*, and *D* in order to maintain their distribution, must forthwith ship their sugars five hundred miles into the territory of refiner *A*. Perhaps the first sale was obtained by granting a concession and so the second sale is made at even a larger concession and the game goes merrily on. Beet sugar pro-

ducers expand and sell sugar in the Eastern states, even in New England, all of which has been considered the territory of the Eastern refiners. The Eastern refiners retaliate and sell more sugar in the Mississippi Valley, thereby forcing more beet sugar East.

As long as quotas are excessive and more sugar is being offered than can be sold, marketing conditions are certain to be bad.

In the light of this picture, which perhaps is not quite as hopeless as has been painted, let us consider our own marketing problems. Honolulu Plantation Company refines its own and Waimanalo's sugar. The local demand is first filled and what remains is shipped and sold at present to a chain store in Los Angeles and the Northwest. As with all offshore sugar, that which is marketed on the mainland is sold at a discount. Eight Hawaiian plantations sell their crops, totalling about 100,000 tons, to the Western Refinery in San Francisco on the basis of the New York market price for raws, less the difference between the cost of marketing the same in New York and the cost of marketing in San Francisco. At present this deduction is $3.50 a ton.

All the other plantations sell their sugars, except for small amounts sold at the plantations, through C. and H. This refinery, which is entirely owned by the plantations selling through it, is operated on a cooperative basis. It handles about 85 per cent of the Hawaiian crop. Some of the sugar is refined at its plant at Crockett, other sugar is refined for its account in New York by an Eastern refinery and the remainder is sold in New York as raws. From the gross proceeds which C. and H. receives from its sales of refined and raw sugars, C. and H. deducts all of its expenses plus 6 per cent on its capital and pays the balance to the plantations pro rata in accordance with the tonnage sold. The 6 per cent deducted is also paid to the plantation stockholders as a dividend. It therefore follows that C. and H. serves as the marketing agency for four fifths or more of the sugar produced in this Territory and since C. and H. is a refinery, a major portion of the Hawaiian sugar industry is directly concerned with the marketing problems of refined sugar.

The plantations now owning C. and H. did not start this refinery as an enterprise for profit in itself but were compelled to establish it in order to assist in the marketing of their sugars. Prior to 1904, when C. and H. was incorporated, a portion of their crops was sold to a refinery in San Francisco and the remainder had to be shipped by sailing vessels around Cape Horn or transshipped by rail across lower Mexico and sold to Eastern refineries. This was far more expensive than shipping to San Francisco. The negotiations for a yearly contract with the San Francisco refinery became deadlocked, the representatives of Hawaii believing that the deduction demanded from the New York market price for raws was excessive, even though it was less than the additional cost required to ship sugar to the Atlantic seaboard. Hence it was decided to build an Hawaii-owned refinery at Crockett.

C. and H. purchased such sugars as it could sell as refined at $5.00 off the New York raw basis. The remainder of the sugars of the C. and H. plantations was not sold through C. and H. as is done at present but was sold direct by the plantations to Eastern refiners at a discount, usually about $2.00 per ton off the New York market price. Its profits were satisfactory and instead of distributing these as dividends they were used in paying off its indebtedness and expanding its plant to

meet the increased demands of the Pacific coast. With the rapidly growing population of western United States, it was believed that C. and H. would soon be able to refine and sell all of the crops of its plantations and its capacity was increased accordingly. This became particularly desirable on account of the excessively high freight rates resulting from the first World War.

In 1920 for the first time in the history of our sugar industry, all of the Hawaiian crop was shipped to San Francisco. That year, however, was a sad year for C. and H. The price of raw sugar soared to unprecedented heights in the spring and summer of the year when a major portion of the Hawaiian crop is being marketed. In May it reached a peak of over $470 a ton. Under the contract, C. and H. had agreed to purchase the sugar at $5.00 off the New York raw basis but could not dispose of the refined until months later. At the close of the year the price of raws was but a little over $100 a ton. The result was obvious. Sixteen years of savings, plus most of the original capital were wiped out. C. and H. had to be financially reorganized and to prevent a repetition of the result of 1920 it was reorganized on the present cooperative basis. During the two decades that C. and H. has been operated as a cooperative the plantations marketing their sugar through it have received on an average $1 or $2 a ton more than those plantations selling their sugar to the Western. In recent years, however, the returns on a comparative basis for the C. and H. plantations have not been as favorable. This is on account of another change in conditions.

The western part of the United States is obviously the natural market for Hawaiian sugars. Increasing the capacity of the C. and H. plant at Crockett so that it could refine all of its Hawaiian crop was logical. Three plants might have been built by adding one on the Northwest and one in Southern California, but at that time practically all Hawaiian shipping was direct to the San Francisco bay region and the unit cost of building and operating one large plant was considerably less. Other conditions which could not have been foreseen have altered the situation. The first of these was the increase in the Hawaiian crop from about 600,000 tons in 1920 to roughly a million tons today. Philippine whites have also cut into the Pacific coast markets to the extent of about 50,000 tons. The third and most important reason of all is the expansion of beets, particularly in the West. During the last fourteen years domestic beet production has increased from 800,000 tons to 1,450,000 tons. In 1926 the beet production of California was 68,000 tons while last year it was 451,000 tons. The increased demand in the West has been filled by other sugars. C. and H. sales of refined in the eleven Western states were slightly less in 1939 than they had been sixteen years previous.

The actual decrease, however, in the sale of Hawaiian sugars on the Pacific coast is greater than indicated. For many years C. and H. sold from 50,000 to 75,000 tons of raw sugar to the Western which in turn refined and marketed it in the West. This, however, was discontinued in 1933 when it was felt inadvisable for C. and H. to furnish its competitor with ammunition for use in its most desirable market. In order to sell its refined, C. and H. shipped sugars farther and farther East. By 1929 its inventories of refined sugars which it was unable to sell became so large that the practice of selling raw sugars to Eastern refineries was once again resumed and has been continued since then.

However, it was apparent that selling raws to Eastern refiners who in turn

marketed these same sugars as refined in the river territory in competition with C. and H. was not entirely sound. It was also considered desirable to attempt to establish a permanent home market for our sugars rather than depend upon our competitors. For this reason, five or six years ago negotiations extending for a couple of years or so were carried on by C. and H. looking towards the purchase of an Eastern refinery. Also, since each refinery considered had its own established distribution, it was believed that the removal of the pressure of the C. and H. sugar which had been squeezed out from the West would have a desirable effect upon general marketing conditions. Unfortunately, for one reason or another, all of these negotiations fell through. As a last resort two years ago, C. and H. entered into an agreement with an Eastern refinery under which the latter agreed to purchase our excess raws and also refine a portion of them for the C. and H. on a tolling basis. With this tolled sugar, C. and H. has entered the Eastern refined market where it is selling something over 100,000 tons annually. This arrangement is not entirely satisfactory since the only customers C. and H. can obtain are those that have been served by other Eastern refineries and this has resulted in retaliatory moves on their part.

Therefore, although the markets of Honolulu Plantation Company and the so-called Western plantations seem fairly secure, the present market of the C. and H. plantations is not entirely satisfactory and the indications are that it will become worse. The plant at Crockett has an annual capacity of about 800,000 tons but C. and H. can only sell 550,000 tons as refined and 100,000 tons of this amount is tolled in the East. Roughly the distribution of the 550,000 tons is about 200,000 tons a year in the West, another 200,000 tons in the river territory and the remaining 150,000 tons in the East and Northeast. With the large overhead costs of its refinery at Crockett, further reductions in the melt of that plant would prove expensive. And yet, with the expansion of beets, more of our sugar is being forced out of the Western market and with the substantial increase in shipping rates from Crockett through the Canal, maintaining the present melt is well-night uneconomic.

The logical solution seems to be the purchase of an Eastern refinery with a distribution large enough for our excess sugars and a reduction in the size of our plant at Crockett. We might then be able to largely withdraw from the river territory which is our most expensive market. The areas most readily served from New York, Philadelphia and Baltimore consume almost half of the white sugars consumed in the United States and because of freighting problems these areas are unattractive to beets. However, the purchase of an Eastern refinery has its complications.

A solution that is often given is that of refining at the plantations as Honolulu Plantation Company does or building one or more refining plants here in Hawaii. Without the existing legal restriction on shipping refined sugar to other parts of our country, which will certainly be removed some day, the advantages of Island refining appear obvious—a lower refining cost plus the ability to ship to any port rather than first to Crockett and then elsewhere. Furthermore, we would be adding another industry to Hawaii which is highly desirable. The major problem is not, however, a reduction in refining or freighting costs but the selling of sugar without breaking down the whole sugar price structure. C. and H. today could refine all of its sugar but simply could not sell it.

And it is open to argument that refining in Hawaii would actually result in increasing our net proceeds. With a plant already at Crockett and its existing overhead and organization, its out-of-pocket refining costs are probably much less than the costs, including additional capital charges, of refining here. Quality is of utmost importance and this would be difficult to maintain with plantation refineries. A reputation for poor quality might prove as expensive as it has for beets. Then too there would be the problem of producing the 34 grades marketed in 135 different forms and sizes of containers.

Freight savings are also not as simple as they appear on the surface. To be sure, we could ship to the Northwest or Southern California direct. But our sugars do not pay the freight from Crockett to Seattle or Los Angeles. San Francisco being a basing point, these freights are added to the price. If we shipped any quantity of refined direct, in all probability beets would establish other Pacific coast ports as basing points and our freight savings would disappear. We could refine here and ship direct to the Gulf for distribution in the river territory but that is our most unfavorable market. Also, supplying areas from Hawaii which are now supplied through Crockett would decrease the melt at our present plant. It would be a robbing-Peter-to-pay-Paul proposition.

Finally, there is the grave question as to whether sugars refined in Hawaii, regardless of quality, would not have to be sold at a discount as has always been the case with all offshore refined sugars and with all beet sugars. This could only be determined by the old method of trial and error and if it proved an error, more than the amount invested in Island refining would be lost. The day may come when refining in the Islands will fit into our general marketing picture, as it seemed to four years ago when the purchase of an Eastern refinery was being considered. Today, however, even without the legal restrictions, it would prove a serious mistake.

And so after having taken you on quite a tedious, rambling trip exploring regions beyond our horizon of the cost of landing raw sugar at market, we have returned home once again. And as is always the case, we are mighty glad to be back in Hawaii Nei. In this other field—the price we receive for our sugar—we find much confusion, bitter antagonism and open hostility. Here we have the opposite—all working together and helping each other in an endeavor to reduce the cost of our product directly by eliminating unnecessary labor or material or indirectly by increased yields and recoveries.

Undoubtedly our most vital cooperative policy is that of virtually selling as a unit, rather than in competition. This cooperation in selling our sugar is and always has been vastly more important, not only to the C. and H. plantations, but to all others as well, than the combined cooperation in all other branches of plantation activities. Its discontinuance would prove fatal to our industry.

Canton Island

By R. H. VAN ZWALUWENBURG

The Clipper plane service, now operated between Honolulu and New Zealand by the Pan American Airways Company, brings into sharp focus the importance of Canton Island as a quarantine station at which to intercept undesirable insects which threaten Hawaii from the South Pacific region. With an entomologist of the Hawaiian Sugar Planters' Association stationed on Canton, a second "filter" (the other being at Midway) now supplements the official quarantine services guarding this Territory against new insect pests.

Canton Island lies about 1670 air miles south-southwest of Honolulu, at about 171° 43′ west longitude and 2° 49′ south latitude. It is a coral atoll—a strip of land encircling a lagoon—and in outline it resembles a porkchop. The land strip, characteristically higher along the ocean shore than on the lagoon side, varies in width from about 75 yards to one third of a mile, and is about 27 miles around. The island measures some nine miles by four, and its highest point is not over 25 feet above the sea.

The outer shore slopes abruptly to the fringing reef, while on the inner shore the slope to the lagoon is gentle, ending in a sandy beach or in low ledges of overhanging coral. Along the lagoon shore are a few small tidal pools, and on the southern part of the island are two large ponds formed by the caving in of undermined coral. Along its outer rim especially, much of the island is piled with large pieces of broken coral tossed up by high seas which now and then break across the narrower parts of the land and pour into the lagoon. In other parts there are extensive areas of bare, unbroken rock; still other parts of the island are covered with sand, and there vegetation is at its best. Occasional fragments of pumice, worn smooth by wave action, are found here and there; they are not of local origin, but reached Canton probably after a long drift westward on the equatorial current.

The lagoon is relatively shallow and studded with coral heads and long, wall-like reefs. Because there are but three breaks in the surrounding land through which water can pass, the movement of water within the lagoon lags behind the ocean tides, and the difference between high- and low-water levels is much less there than outside. The water within the lagoon has a higher salt content than the sea water.

There is no fresh water on Canton and residents depend upon stored rain water. There is a great variation in rainfall from year to year. The records of the British station, which have been maintained continuously since September 1937, show the following total rainfall:

1938	8.71 inches
1939	18.47 "
1940 (first 5 months only)	30.25 " *

*Since this was written, R. R. Danner reports that the rainfall during 1940 totalled 69.3 inches; of this, over 18 inches fell during December.

The distribution of rain appears to have been fairly good during the past year and a half. Temperatures show comparatively little daily or seasonal range; maximums are in the lower nineties. The island lies within the equatorial belt of relative calms; the highest wind velocity recorded is 30 m.p.h.* Prevailing winds are from the east-southeast.

Canton is the largest of the Phoenix Group and, although perhaps visited from time to time by Polynesian seafarers, was probably never long inhabited. The exact date of its discovery in modern times seems to be unknown. The island was not marked on charts published in London in 1791, but is named in a report filed with the United States Secretary of the Navy in 1828. Early in the nineteenth century it was known variously as Mary, Balcout, Balcut or Swallow Island. Its present name became current after the whaling ship *Canton,* of New Bedford, struck and

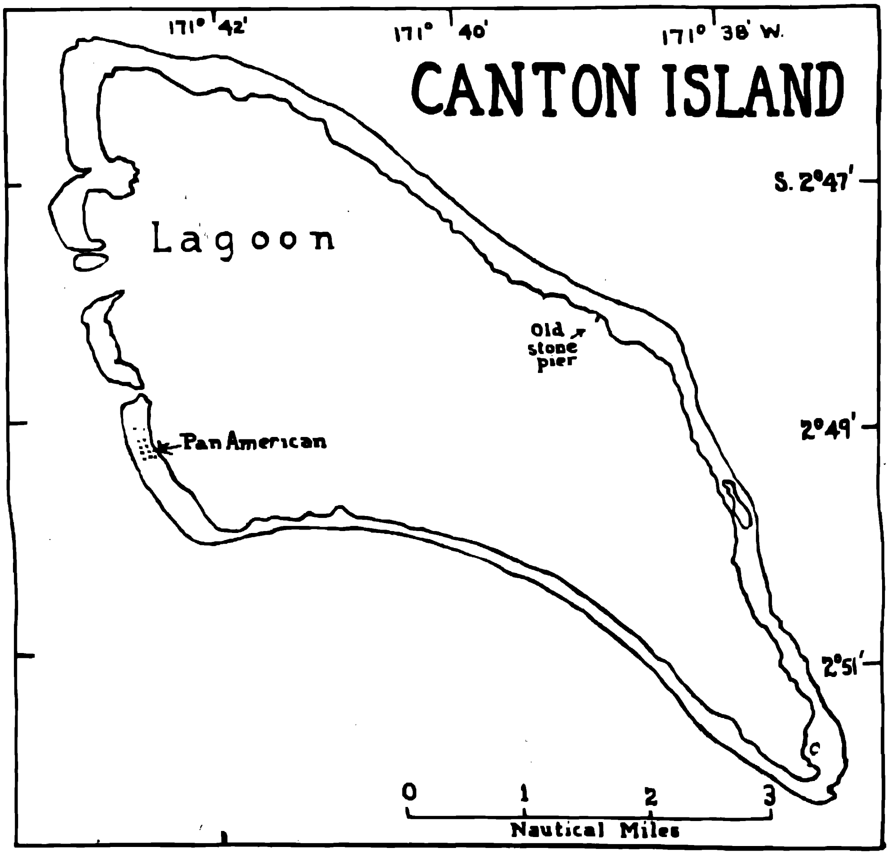


Fig. 1. Map of Canton Island adapted from Bryan.

sank on its western coast in March 1854. During the eighties an English company worked the guano deposits on the east side of the lagoon. (The "stone pier" shown on the accompanying map marks the location of the guano diggings.) In 1916 a British trading company took a long lease on the island, but appears to have done

*H. K. Graves states that in December 1940 unprecedented winds from the west attained a velocity of 55 knots an hour.

nothing further than to plant some coconuts. When trans-Pacific aviation gave the island importance American and British claims came into conflict. These have now been adjusted on the basis of joint occupancy for a specified term of years. At present there are over 50 residents on Canton, including the P.A.A. personnel and a smaller group at the British settlement. The airport is fully equipped with power plant, machine shop, radio station, personnel quarters, water storage facilities, a small hospital and a modern hotel. Planes alight and take off at Canton on the lagoon; they are moored at the end of a pier some 50 yards from shore.

The native flora of Canton is comparatively simple. E. L. Caum has arranged the known species as follows:

Graminae
- *Digitaria pacifica* Stapf
- *Eragrostis whitneyi* Fosberg var. *typica* Fosberg
- *Lepturus repens* R. Brown

Palmae
- *Cocos nucifera* Linnaeus

Nyctaginaceae
- *Boerhaavia diffusa* Linnaeus

Aizoaceae
- *Sesuvium portulacastrum* Linnaeus

Portulacaceae
- *Portulaca lutea* Solander

Lauraceae
- *Cassytha filiformis* Linnaeus

Zygophyllaceae
- *Tribulus cistoides* Linnaeus

Simarubaceae
- *Suriana maritima* Linnaeus

Tiliaceae
- *Triumfetta procumbens* Forster

Malvaceae
- *Sida fallax* Walpers

Convolvulaceae
- *Ipomoea pes-caprae* (Linnaeus) Roth
- *Ipomoea grandiflora* Lamarck

Boraginaceae
- *Cordia subcordata* Lamarck
- *Tournefortia argentea* Linnaeus

Rubiaceae
- *Morinda citrifolia* Linnaeus

Goodeniaceae
- *Scaevola frutescens* (Miller) Krause

Whether or not the coconut is "native" to Canton may be debatable; certainly all of the few specimens there today were planted within recent times. Five large

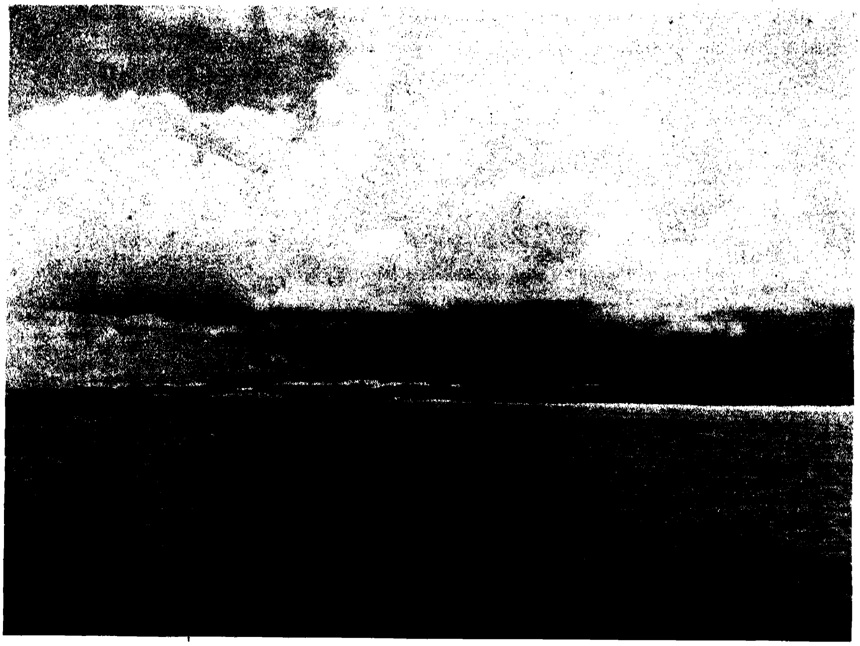


Fig. 2. Canton Island settlement as seen looking southwest from the lagoon. British settlement next to coconut trees; P.A.A. buildings center and left.

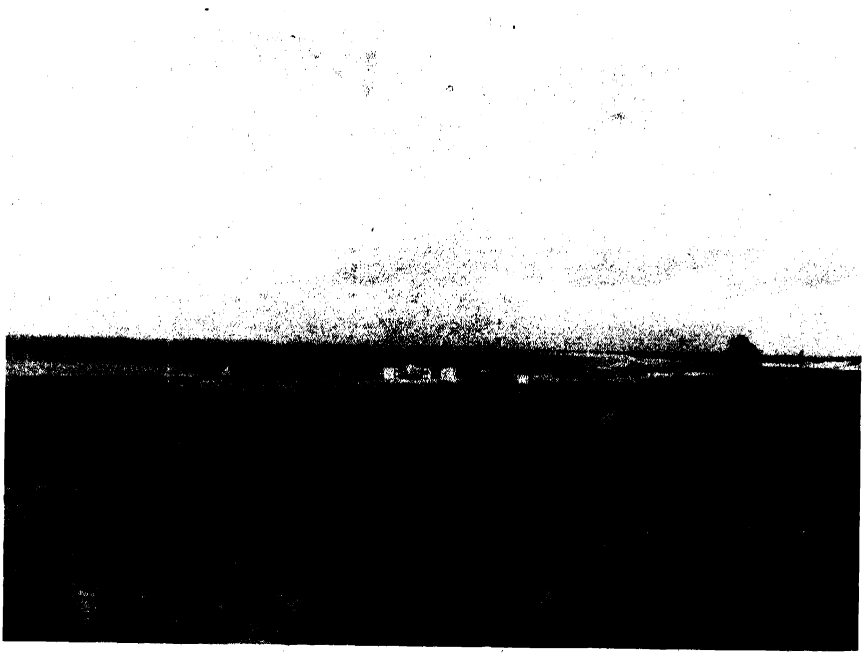


Fig. 3. View from lighthouse tower, Canton Island, looking south-southeast toward lagoon. British settlement center; P.A.A. hotel extreme right.

trees standing near the British settlement and two others at the north end of the island are believed to have been planted about 1916. An extensive planting was made in 1937 west of the lagoon and, although the plants have made little growth, many survive.

Coconuts excepted, the island's most conspicuous vegetation consists of clumps of Cordia (kou), Tournefortia (tree heliotrope) and Scaevola bushes. These are often 10 to 15 feet tall, and usually have many dead, bare branches above the green growth nearer the ground. A nearly solid growth of Scaevola, occupying the width of the island, extends for about two miles along the southwest coast. As a probable result of the good rains of the past year or more, the richer parts of the island are at present covered with an excellent growth of Sida, Portulaca, Triumfetta, Boerhaavia and bunch grasses (Lepturus and Digitaria). In less favorable spots Triumfetta often occurs alone. Eragrostis and Sesuvium occupy low hollows. Suriana, a woody shrub, usually grows very close to the ground, but in one case a clump of it attains a height of some ten feet. Near the guano diggings is growing the single specimen of Morinda (noni) at present known on the island. There too, occurs a white-flowered Ipomoea, while another species, the well-known beach morning-glory, occurs on the lagoon shore near the British station. Cassytha is a vine-like parasitic plant suggestive of dodder. It is probable that the thriving state of the native vegetation, as it existed during the latter months of 1940, is not the usual condition on Canton. The first P.A.A. construction force to arrive in the spring of 1939 reported that the area now waist high in Sida and associated plants was then practically a desert.

The Pan American is doing extensive planting, using native materials as well as promising foreign plants like seagrape and ironwood. What effect a prolonged drought will have on these plantings remains to be seen, but it is hoped that many of them will by then be sufficiently established to survive water shortages. Storage facilities for water are not adequate to care for large numbers of plants should prolonged droughts occur.

Importations of soil from Oahu have resulted in the recent establishment on Canton of several weeds such as *Emilia sonchifolia,* three species of Euphorbia, *Leucaena glauca,* nutgrass and amaranth. A few grasses, including bermuda grass, have also gained a foothold in the same way.

The new arrival at Canton is apt to notice first the fish which crowd about the wharf where the planes are moored. They are a spectacular feature of the lagoon life, and their almost infinite variety would require a lifetime for thorough study. Despite the dynamiting which was necessary to prepare runways for the planes, the fishing in the Canton lagoon is still incredibly rich. Ulua, redsnapper and rock cod are a few of the species in the lagoon, while outside are also to be had barracuda, yellow-finned tuna and many other fish. Sharks are abundant in both lagoon and ocean; known locally as "sand sharks" they grow to a length of six feet or more. Small ones venture into shoal water within a very few feet from the shore. They appear inoffensive under ordinary circumstances; at any rate, Canton residents commonly swim in the lagoon where these sharks are frequent.

Marine birds form nearly all of the island's numerous bird life. Nesting in the higher clumps of kou and tree heliotrope are two or more kinds of gannets (booby birds), while the frigate birds keep more or less apart in lower growths of Suriana

Fig. 4. Scaevola clumps, southwest coast of Canton; Triumfetta in foreground.

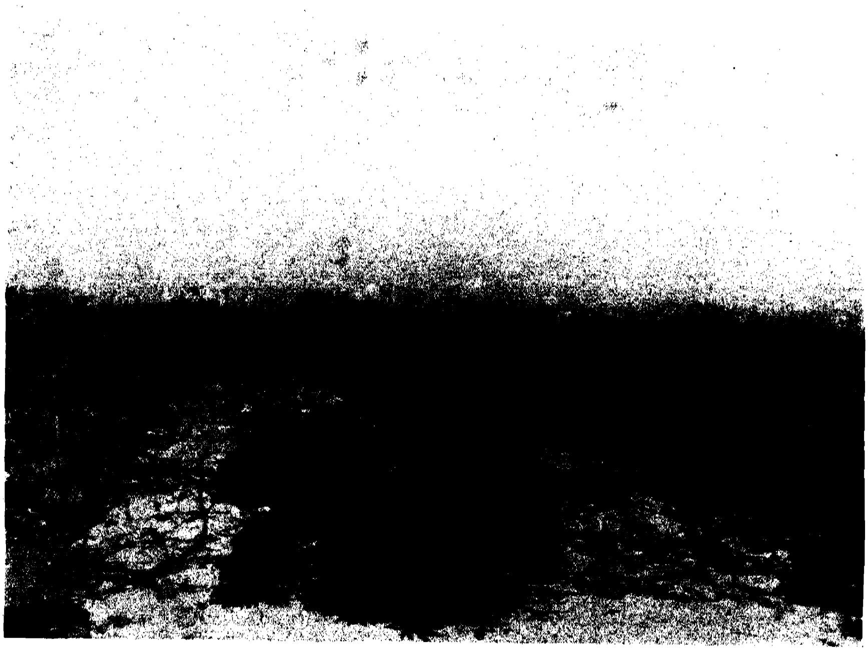


Fig. 5. Scaevola thicket, southwest coast of Canton; dead branches are characteristic of nearly all of the shrubs.

and Scaevola. The blue-faced booby lays its egg on bare ground without benefit of nest. The white "love tern" makes no nest, and is inclined to lay its egg on the precarious pinnacle of a rock. Loud squawks from the less common bos'n bird are meant to warn intruders from the rock ledges under which that bird nests. Many of the birds, particularly the gannets, are so tame that they are easy subjects for the camera. Long-billed curlews frequent the reef at low tide, while a variety of the familiar golden plover busies itself in the grass, the only one of the birds, apparently, to show any interest in insects.

Wherever there is good cover, the small, ground-nesting Polynesian rat is present in astonishing numbers, and it occurs more or less all over the island. Besides robbing domestic foodstuffs, it feeds on vegetable food such as the bark of twigs, and the fruits and flowers of Scaevola, climbing well above ground in daylight with little show of fear.

From the standpoint of our quarantine it is the insect fauna that is of greatest moment. Not only is it important that we know what insects now on Canton should be guarded against, but also that we be able to recognize if any dangerous additions to the fauna occur there in the future. Much of the writer's time from July 25, 1940 to early October was devoted to a survey of the insect life. As a result of this and the earlier work of D. B. Langford, a list of over 60 native and immigrant species of insects and related forms was compiled. Since then, R. R. Danner has added considerably to the list, but it seems probable that the completed total will not exceed 100 species.

At present there are few insects on Canton which would be undesirable additions to the Hawaiian fauna. The most important of these is the noctuid moth *Prodenia litura* (Fabricius), known, with a long list of economic food plants, from many Pacific islands. Another is an unidentified cicadellid leafhopper associated with Boerhaavia; this belongs to a distinctly undesirable group of insects. Still another is the arctiid moth *Utetheisa pulchelloides* Hampson, the caterpillars of which make Tournefortia foliage unsightly by their feeding. Attached to kou is a large noctuid caterpillar, *Achaea janata* (Linnaeus), belonging to a group some species of which, as adults, damage citrus fruits by piercing them with the proboscis; this is a species which would most certainly not be welcome in Hawaii. Practically all of the insects boarding the planes at Canton are flies, some of them already here in Hawaii, and none of economic importance.

The absence of the usual insect-parasite complex is one of the most striking entomological features of Canton. A species of Baeus, a hymenopteron presumably parasitic in spider eggs, was once collected by Mr. Langford in sweeping low herbage, but has not been found since or bred from any of the numerous spider eggsacs collected for observation.* With this probable exception there appear to be no parasites of insects. There are none of the hymenopterous or dipterous parasites usually associated with a numerous and varied population of leaf-feeding caterpillars. The non-native scale insects, brought in on imported plants during recent years, likewise appear to be without insect parasites.

Canton is almost unique in having at present no mosquitoes, and apparently no

*The Baeus from Canton, identified by Dr. F. X. Williams, seems to be identical with the species introduced into Hawaii in 1939 from California (*Baeus californicus* Pierce). There is good reason to believe that the specimens credited to Canton were not actually collected there, but instead were accidentally taken there in laboratory glassware from Honolulu.

Fig. 6. Abandoned guano diggings on east side of lagoon. Lepturus grass in foreground, Scaevola bushes in middle distance and Tournefortia in rear. Low areas often have Eragrostis grass.

Fig. 7. Blue-faced booby, south of P.A.A. settlement, ~~Canton~~. Most of the ground is covered with Triumfetta, with scattered bunch grass and Sida.

fleas. Mosquitoes are very numerous at Noumea, the first P.A.A. base south of Canton, and Culex and Aedes adults are almost constantly being found dead in planes arriving at Canton from the south. In bringing planes to the mooring at the landing float one or more hatches must be opened before any contact is made with the shore. Therefore keeping the island free from mosquitoes of necessity depends very largely upon the efforts of the flight stewards, and the care with which they spray the planes while en route. It is a pleasure to record their active interest in this important matter, and the thoroughness with which they spray the planes approaching Canton. Mosquitoes occur in both New Caledonia and Hawaii which could breed readily on Canton in rain barrels and in empty containers discarded over wide areas near the airport settlement. Tidal pools would probably not support wrigglers of these species because of the high salinity of the lagoon water with which they are renewed at each tide.

Although there are on Canton three dogs which certainly were well stocked with fleas when brought to the island, search for these parasites during the writer's stay was uniformly unsuccessful. Nor did any of the rats appear to harbor fleas. Rats are often seen to scratch themselves, but this seems due to lice and perhaps other parasites, and not because of fleas. Perhaps the scarcity of organic matter in the sandy soil does not afford enough food for development of flea larvae. That their failure to multiply is not due to lethal soil temperatures was demonstrated by soil readings made during the hottest hours of an August day.

There are numerous short references to Canton scattered widely in a variety of publications, but the only articles known to the writer which are at all extensive are the following:

Bryan, E. H. Jr., 1940. The meager vegetation of Canton Island. Paradise of the Pacific, 52: 26–27, 2 figs.

Gardner, Irvine C., 1938. Crusoes of Canton Island. The National Geographic Magazine, 73: 749–766.

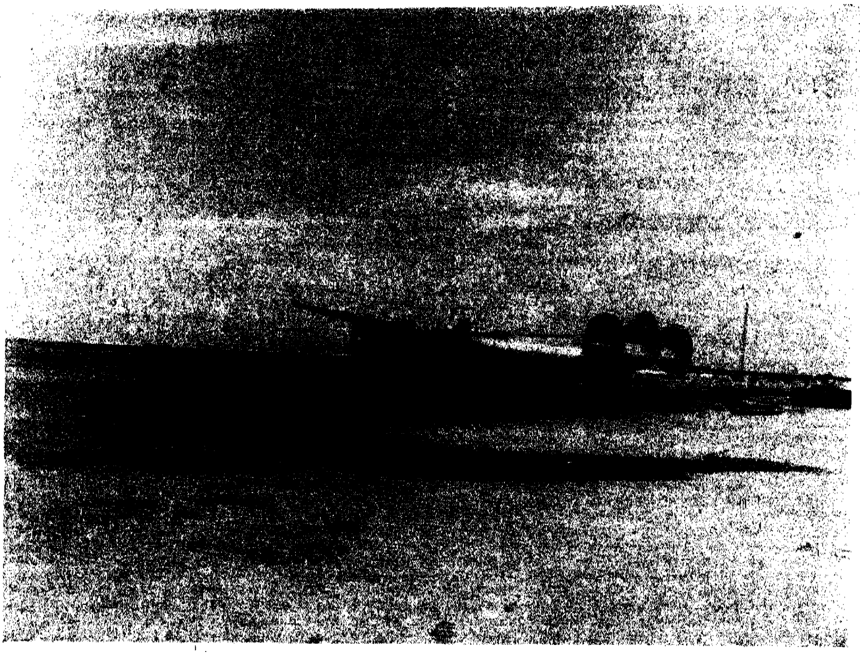


Fig. 8. American Clipper moored on lagoon, Canton Island. The landing float some 50 yards from shore is at the end of a pier, part of which is visible at the right.

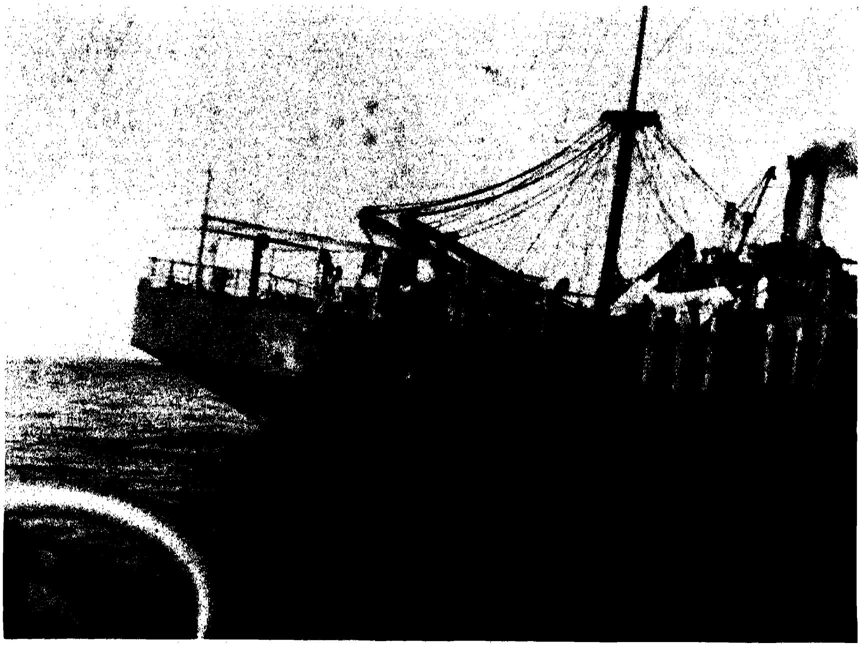


Fig. 9. S. S. Admiral Day, Canton Island, September 21, 1940. This ship ran fast aground on the northeast coast of the island the night of September 18, and was abandoned 12 days later after water had flooded the engines. According to recent reports, the Admiral Day has now broken up and very little of it is visible on the reef.

Observations on Insect Pests in Samoa Which Are Not Yet Known to Occur in Hawaii

By O. H. Swezey

While accompanying E. C. Zimmerman of the Bernice Pauahi Bishop Museum on an entomological exploration trip to Samoa, May 27 to September 5, 1940, considerable definite information was obtained on dangerous crop pests which are not now present in Hawaii. Some of these would be very destructive in Hawaii if they should gain a foothold here and become generally spread. It is to our advantage to know of their habits and of their presence in this neighboring group of islands, which is now only five days away by steamer. Continuous vigilance should be maintained to prevent these pests from reaching our shores.

These pests are here listed according to the crop or food plant which they particularly infest. Names have already been secured for most of them, but are still lacking for a few. In the list are 70 species, a dozen of which were not previously recorded from Samoa.

Sugar Cane

Sugar cane is not grown to any great extent in Samoa, there being only small patches in the villages. The tops are used to thatch the native house (fale), and several varieties, mostly with small diameter stalks, are thus used. A larger red variety is used for eating.

Perkinsiella vitiensis Kirkaldy

This species of leafhopper is closely related to the sugar cane leafhopper in Hawaii. It occurs also in Fiji, where it is considered the transmitter of the Fiji disease of sugar cane. This disease is known in Samoa also. The leafhoppers were found to be not very destructive in Samoa, although occasional neglected patches of cane showed very numerous egg-punctures in the midribs. The leafhoppers themselves were scarce, both as adults and as nymphs. Two kinds of egg parasites were reared from leafhopper eggs. The rarer one was *Paranagrus optabilis* Perkins, and the more abundant one was *Ootetrastichus beatus* Perkins. The round exit holes where the latter had issued were often very abundant. Counts of these exit holes in 10 leaves gave a range in number from 20 to 65 per leaf.

Neomaskellia bergii (Signoret) (Figs. 1 and 2)

The widely distributed (Samoa to Java and Mauritius) sugar cane aleurodid was usually found in small colonies. Occasionally there was a larger colony which almost covered the under surfaces of many leaves in the same stool of cane. No parasites were found, but on two occasions several caterpillars of *Cryptoblabes proleucella* Hamps., a phycitid moth, were found feeding on the aleurodids. The caterpillars fed beneath a thin web. Several moths were reared. One colony was found on *Miscanthus*.

Cosmopteryx dulcivora Meyrick (Fig. 4)

The midrib leafminer is the slender yellow larva of a tiny moth. It bores for a considerable distance longitudinally in the midrib, often in a zigzag manner, so that the midrib is rendered useless and turns a reddish color. Affected leaves are usually conspicuous. Larvae and pupae were collected, but only one moth was reared. This species occurs also in Fiji. It was not recorded in "The Insects of Samoa."

Melanitis leda solandra (Fabricius)

This butterfly in one or another form is distributed widely in China and Malaya, and also in the Philippines, Guam and other Pacific islands. Its large green caterpillar was commonly found on the cane plot of the Experimental Farm at Taputimu, Tutuila. The beautiful green chrysalids were also seen on the leaves, and the butterfly was reared. It was also reared from *Miscanthus,* the caterpillars being found on this plant in several localities. It is reputed to feed also on corn and other grasses.

Corn

Scarcely any corn is grown in Samoa, hence there was little opportunity for observing insects associated with it. Small patches were seen in only two localities.

Phytomyza spicata Malloch

The corn leafminer is the maggot of a tiny black fly, which is known in Fiji and Guam. Very little evidence of it was seen on corn in Samoa. It was very abundant on Job's-tears, and also found on *Miscanthus,* Bermuda grass, *Eleusine indica,* and no doubt could be found on other grasses. Chalcid parasites were reared on several occasions.

Marasmia trapezalis (Guenee) (Fig. 5)

This is the leafroller which I found so abundant on corn in Guam in 1936. It has a wide distribution in the tropical regions of South America, Africa and India, and also in Malaya and across the Pacific to the Marquesas. I did not find it on corn in Samoa, but did find it quite common on *Miscanthus.* A braconid parasite was reared from one lot of caterpillars.

Marasmia venilialis (Walker) (Fig. 3)

On one occasion this grass leafroller was reared from corn. It was very abundant on *Paspalum conjugatum,* Job's-tears and also on other grasses. This is another widespread leafroller, occurring in Africa, India, Australia, Solomon Islands, Borneo, Guam and Fiji.

Adoretus versutus Harold (Fig. 10)

This beetle is related to *Adoretus sinicus* in Hawaii, and has the similar nocturnal habit of feeding on foliage. Corn leaves showed results of their feeding. Many other plants, ornamentals, shade trees and forest trees were badly eaten by these beetles. This is the beetle whose larva, or grub, has ~~been~~ injurious to cane roots in Fiji.

Coconut

The coconut tree has many kinds of insects feeding on it in one way or another, the following six species of which do not occur in Hawaii.

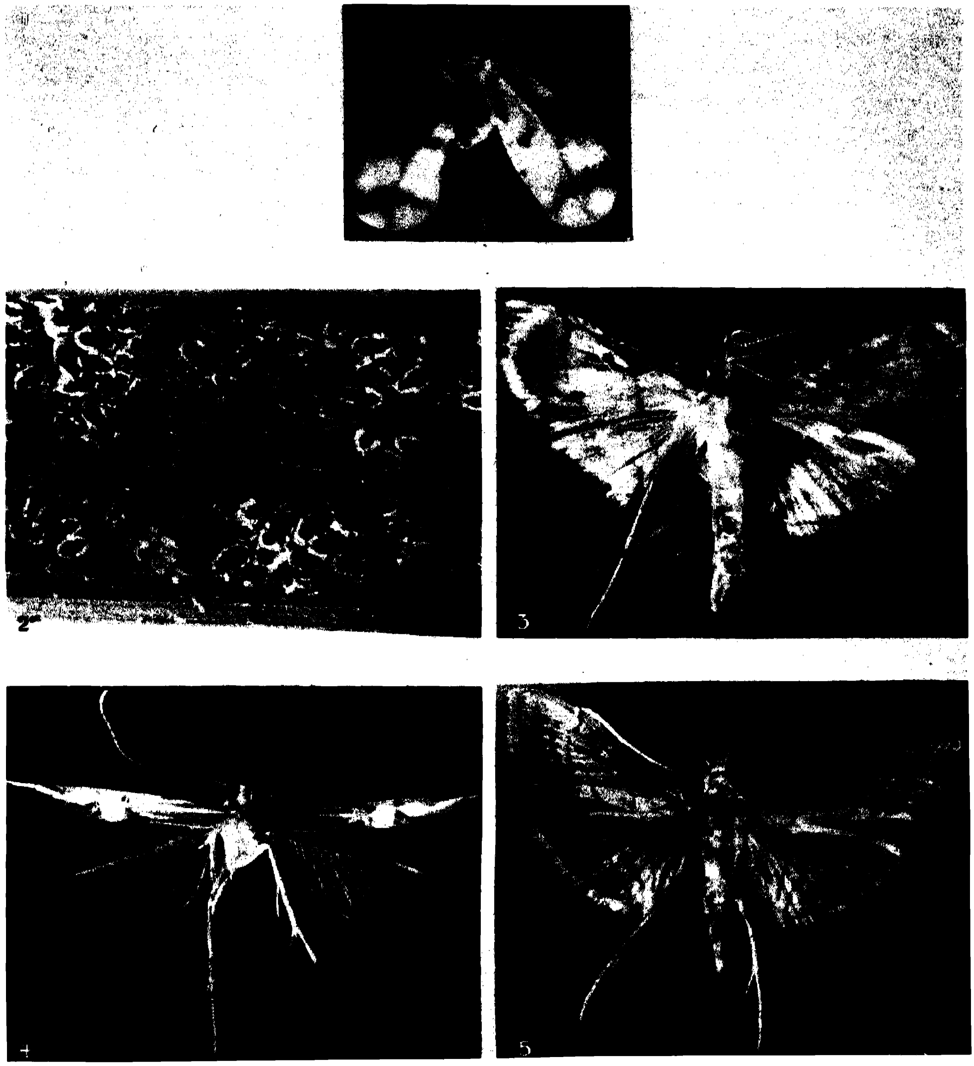


Plate 1

Fig. 1—*Neomaskellia bergii*, cane aleurodid. × 20. Fig. 2—*Neomaskellia bergii*, colony of young on cane leaf. × 6. Fig. 3—*Marasmia venilialis*, grass leafroller. × 4. Fig. 4—*Cosmopteryx dulcivora*, midrib miner of sugar cane. × 8. Fig. 5—*Marasmia trapezalis*, corn leafroller. × 3.5.

Oryctes rhinoceros (Linn.) (Fig. 6)

The large notorious rhinoceros beetle is very destructive to the coconut tree. The adult beetle feeds in the top where it makes large burrows among the soft tissues which results in very ragged leaves when they finally expand, and sometimes

causes the death of the tree. By methods of control the beetles are prevented from doing their worst damage, and badly injured trees are not particularly numerous at the present time. Their enormous larvae or grubs are found in and beneath rotten logs on the ground and in stumps. The best method of control is searching these out and destroying them. Traps are made by placing split coconut logs on the ground to attract the beetles for oviposition, examination being made at intervals, and whatever beetles or grubs found are destroyed. This beetle occurs throughout Malaya, Philippines, China, Siam and India. It is said to have been introduced into Samoa in 1910.

Promecotheca reichei Baly (Fig. 8)

The larvae of this beetle are leafminers. There are many related species in the various localities where coconuts grow. This species is known in Tonga and Fiji. It has blue elytra with anterior third yellow. We found its work in the coconut leaves of both young and also tall trees at the U. S. Naval Station, Pago Pago. The mines were very abundant in the leaves. In some leaves cut from a tall tree every leaflet had mines, from one to six per leaflet. All were old mines, none having living material. At another time, of a lot of mines examined, 83 per cent had had parasites issue from them, as shown by the tiny round exit holes in the leaf. No living material was found in any examination of mines. Perhaps this beetle and its parasites are seasonal, and this may have been the wrong season as we were at Pago Pago during August. No evidence of the work of this beetle was seen on any other part of the island, nor on Upolu.

At the naval station other kinds of palms were also affected. The mines were found in leaves of the royal palm, *Pritchardia pacifica*, and two other palms. The mines show up as dead streaks in the leaflets.

Graeffea crouani (Le Guillou)

This is a green, elongate, long-legged insect commonly called the walking-stick insect. It is often commonly found on coconut leaves where it feeds, eating large notches in the margins of the leaflets and giving the leaves a ragged appearance. It occurs also in Fiji and Tonga and is sometimes recorded under the name *Graeffea coccophaga*.

Pseudococcus cocotis (Maskell)

A mealybug which occurs especially on young coconut plants.

Agonoxena argaula Meyrick (Fig. 15)

A small buff-colored moth whose larvae feeding singly beneath a slight web on the underside of coconut leaflets produce short, narrow streaks of dead tissue where they have eaten off the under part of the leaf. All of the mature leaves are spotted with these streaks. Soon after the new leaves are fully expanded, the small caterpillars begin feeding on them. The other palms mentioned above are also somewhat eaten by these caterpillars. On the island of Upolu, two native palms in the mountain forests had their leaves very much eaten. A braconid parasite (*Apanteles*) was reared from cocoons of this moth. This moth occurs also in Fiji and the Ellice Islands.

Trachycentra calamias Meyrick

Caterpillars of this medium-sized grayish moth were found feeding in the living tissues of the top of a coconut trunk where the rhinoceros beetle had been burrow-

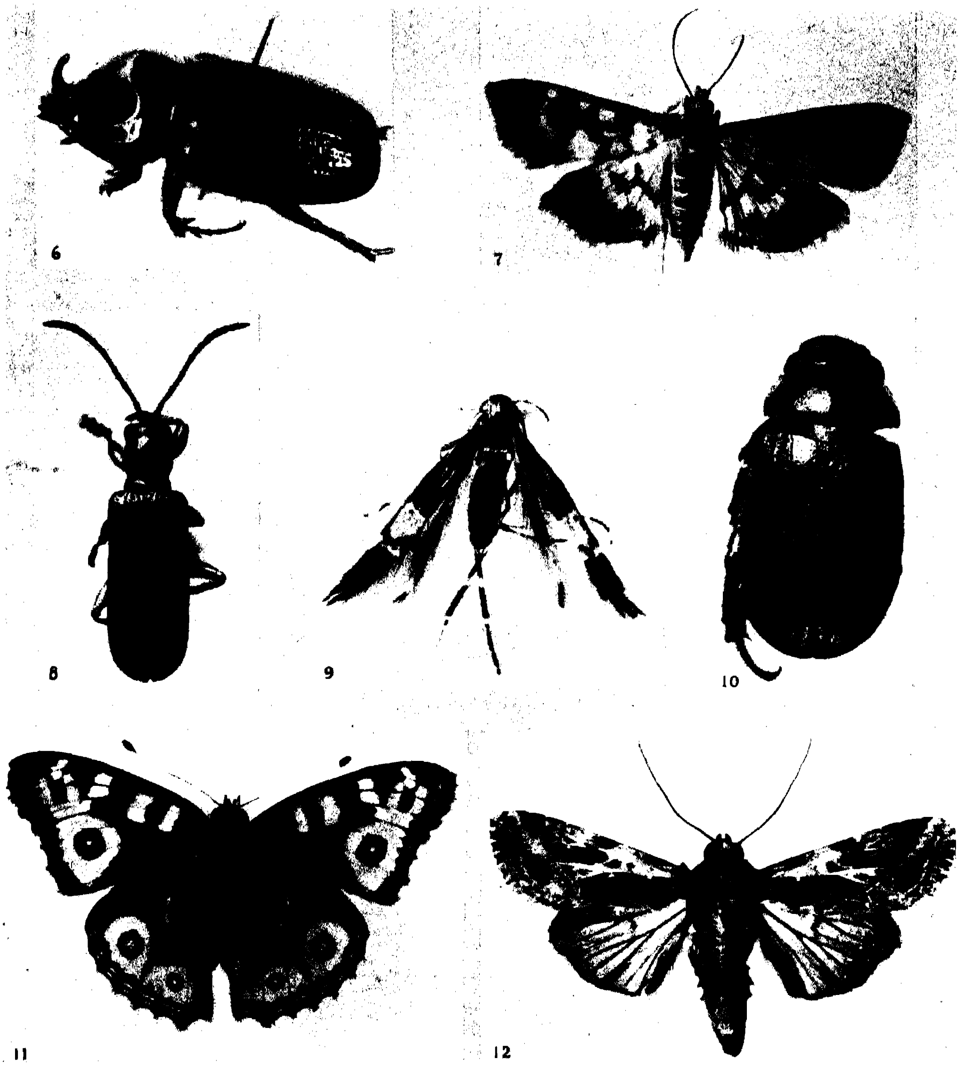


Plate 2

Fig. 6—*Oryctes rhinoceros*, rhinoceros beetle. × 1.5. Fig. 7—*Nacoleia diemenalis*, bean leafroller. × 3. Fig. 8—*Promecotheca reichei*, coconut leafminer. × 4.5. Fig. 9—*Cosmopteryx mimeticus*, nutgrass leafminer. × 8.7. Fig. 10—*Adoretus versutus*, Fijian cane root grub. × 7. Fig. 11—*Precis villida villida*, butterfly whose caterpillars were feeding on sweet potato. × 1.3. Fig. 12—*Prodenia litura*, taro moth. × 2.

ing also. Some of the larvae were feeding in the mass of rotten fibrous material of the dying tree. The older caterpillars were enclosed in elongate brown cases on which they finally place a covering of numerous overlapping fibers placed longitudinally. One end is eventually attached in a convenient place and transformation

to the moth takes place within. This moth was also reared from cases found beneath old banana leaf sheaths. One was also reared from a larval case beneath rotten bark of an *Erythrina* log. This moth occurs also in Fiji and Tonga.

Banana

Nacoleia octasema (Meyrick) (Fig. 18)

The banana scab moth is very destructive everywhere in Samoa. The caterpillars feed among the young bananas on the bunch, eating the skin of many, which gives them a scabby, unsalable appearance when mature. In many cases the caterpillars eat into the young fruits entirely spoiling them, the whole bunch often being ruined. Damage is checked by dusting with surphur at the proper time. Great quantities of bananas are shipped from Apia to New Zealand. In packing for shipment, all bananas are cut from the bunch in order to sort out and discard the scabby and injured ones, while the perfect ones are packed in cases. If this moth ever became established in Hawaii, similar methods would have to be resorted to for bananas shipped to California, instead of the present method of wrapping the whole bunch for shipment. This pest causes great losses to the growers in Samoa, and it occurs also in Fiji, Queensland and Java.

Cosmopolites sordidus (Germar)

This is a large black weevil about the size of the sugar cane beetle borer. The larvae feed in the base of banana plants. We did not find them common enough to cause significant injury. It occurs very widely in Brazil, West Indies, Queensland, Fiji, Guam, Philippines, and Java. In some of these places it is very injurious.

Prodenia litura (Fabricius)

Caterpillars of this moth feed to some extent on banana leaves.

Taro

Prodenia litura (Fabricius) (Fig. 12)

This widely spread moth was the worst taro pest we observed in Samoa. It is a pest the world around in the tropics, feeding on many kinds of cultivated plants. On taro the eggs are deposited in clusters of several hundred on the underside of the leaf. The young larvae feed gregariously for awhile, then scatter to nibble here and there, but eventually as they reach their full growth skeletonize the leaves so that only the main ribs are left. Such leaves are conspicuous in the taro patches, and at times a great deal of damage is done. Other plants on which I found caterpillars are: banana, tobacco, sensitive plant, and *Ipomoea pes-caprae*. A few caterpillars were found parasitized by *Euplectrus*.

Hippotion celerio (Linnaeus)

Another widespread moth occurring in Europe, Africa, India, Java, Borneo, Timor, Australia and Fiji. It is one of the smaller-size hawkmoths. The eggs are laid singly on taro leaves. A few of the green caterpillars were found in most taro patches, and they are said to sometimes defoliate the plant completely, and to feed on other plants related to taro.

Sweet Potato

Herse convolvuli (Linnaeus)

This is the morning-glory hawkmoth which is widely distributed throughout the Pacific islands, with the exception of the Hawaiian Islands where a related and

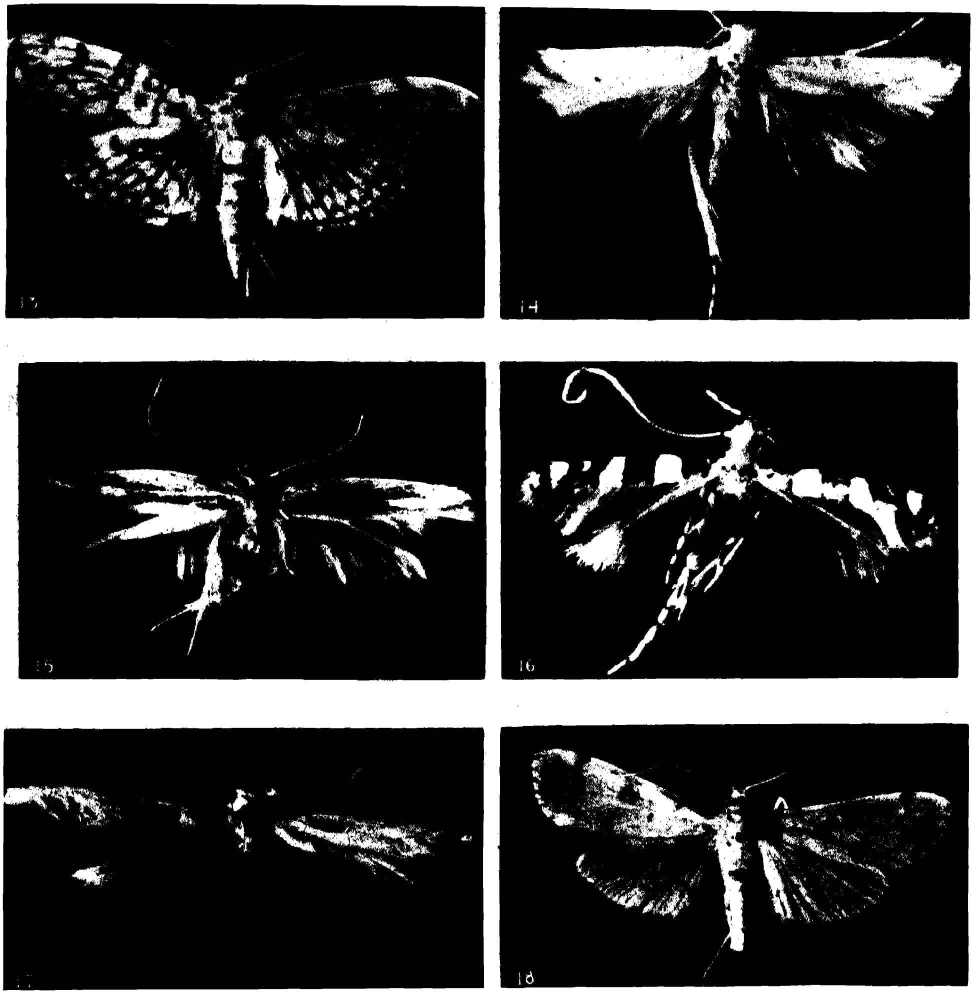


Plate 3

Fig. 13—*Sylepta derogata*, hau leafroller. × 2.5. Fig. 14—*Thiotricha strophiaema*, Terminalia leaf perforator. × 6. Fig. 15—*Agonoxena argaula*, coconut leaf moth. × 4. Fig. 16—*Acrocercops homalacta*, sweet potato leafminer. × 9. Fig. 17—*Pachyrhabda amianta*, bird's-nest fern moth. × 7.5. Fig. 18—*Nacoleia octasema*, banana scab moth. × 2.5.

closely similar species from America, *Herse cingulata* (Fab.), prevails. The caterpillars of both species feed on sweet potato leaves, this plant belonging to the morning-glory genus *Ipomoea*. The species in Samoa was found to be doing no appreciable injury to sweet potato.

Precis villida villida (Fabricius) (Fig. 11)

This butterfly was reared from black spiny caterpillars feeding on sweet potato leaves, though not abundant. It occurs also in Tonga, Ellice Islands, Swain's Island and Tokelau Islands. It has been previously recorded from the strand plant *Scaevola koenigii.*

Bedellia sp.

This is a very small moth whose larvae are leafminers in sweet potato. It is related to the sweet potato leafminer in Hawaii, but is a distinct species, as shown particularly by quite a different larva. It was not common. Parasites (*Apanteles* sp.) were reared.

Acrocercops homalacta (Meyrick) (Fig. 16)

This is another leafminer, larger than the preceding. It occurs also on morning-glory of various kinds, particularly on a large-leaved species with white flowers which is probably *Operculina turpethum.* It was quite abundant in the largest productive garden which we visited. It is very closely related to, and may possibly be identical with, a species (*Acrocercops prosacta*) recorded as a leafminer on sweet potato in India. A species of *Apanteles* was reared from mines.

Ercta ornatalis (Duponchel)

A small pyralid having green caterpillars which feed on the underside of the leaves. It was more common on several species of morning-glory.

Cassida strigula Montrouzier

A tortoise-shell beetle which feeds on morning-glory leaves as well as on sweet potato leaves. Common in places, but not enough for significant injury. It occurs also in New Guinea and Australia.

BEANS

Nacoleia diemenalis (Guenee) (Fig. 7)

The bean leafroller with wide distribution in the tropics. The caterpillars feed between webbed-together leaves of several kinds of beans and are sometimes quite destructive. An *Apanteles* parasite was reared, also a small tachinid.

Acrocercops sp.

The bean leafminer, the same as was prevalent in Guam. It is very abundant on some kinds of beans in Samoa.

Acrocercops sp.

A different species of leafminer was found and reared from leaves of an unidentified wild bean vine. Sometimes there were two larvae in the same mine. They pupated in slight cocoons in the mines, whereas larvae of the other species issued to produce their cocoons on the surface of the leaf.

Jamides argentina (Prittwitz)

A beautiful blue butterfly whose larvae feed within buds and blossoms of *Vigna marina,* a yellow-flowered bean vine on the beach. One larva would destroy quite a number of blossoms.

Margaronia mysteris (Meyrick)
Phostria oconnori Tams

These two moths were reared from caterpillars feeding between webbed-together leaves of wild bean vines in the mountain forests. *Strongylodon lucidum* and *Mucuna gigantea* were both present, and it was not always possible to distinguish which of these vines was the host of the caterpillars collected. A tachinid maggot issued from one caterpillar. The first-named moth was described from the New Hebrides; the second from Samoa.

Brenthia catenata Meyrick

A small dark moth whose caterpillars were abundant and feeding on leaves of a wild bean vine, *Strongylodon* or *Mucuna*. Transformation took place in white spindle-shaped cocoons on the surface of the leaves.

Azazia rubricans (Boisduval)

A medium-size gray moth reared from green semilooper caterpillars on *Vigna*. Twenty *Apanteles* parasites issued from one caterpillar. This moth is recorded from Africa and India, and also from Java and other Pacific islands, but was not previously recorded from Samoa. Perhaps it has become established recently as it is not very abundant yet. It is a minor pest of several kinds of beans in India.

Green pentatomid bug (an undetermined species)

This large bug was found abundant on beans, as well as on other garden plants, and is sometimes quite injurious.

Cucurbits

Margaronia indica (Saunders)

This leafroller moth occurs on cucumber but was not common enough to be injurious. It is widely distributed in Africa and India, and in Malayan and Australian regions. We found it in Guam in 1936.

Agromyzid leafminer (undetermined)

A very small black fly was reared from mines in leaves of a wild cucumber. It was found abundant in several places. The puparia were formed within the mines, and figitid parasites issued from some of the puparia.

Epilachna 28-punctata (Fabricius)

This large phytophagous ladybeetle ranges from the Orient to Australia and the Pacific islands. It feeds on many plants, particularly the leaves of pumpkin vines which are sometimes entirely destroyed. The adults as well as the larvae feed on the leaves.

Aulacophora similis Olivier

This moderate-size leaf beetle was described from New Guinea. We found it common on squash and cucumber vines.

Green pentatomid bug (undetermined)

This large bug is often found on cucurbits as well as other garden plants.

Tobacco

Heliothis assulta Guenee

The caterpillars of this pretty, medium-size moth were very abundant on tobacco plants, every plant of the most pretentious planting which we saw had been injured, and daily hand picking had been resorted to. These caterpillars also attack green tomatoes. I reared two moths from caterpillars feeding on the green fruits of *Physalis minima,* closely related to our poha in Hawaii. Each caterpillar would require a large number of fruits for its maturity.

Prodenia litura (Fabricius)

Caterpillars of this moth were found on tobacco.

Guava

Dacus psidii Froggatt

This is the guava fruitfly. We found strawberry guavas infested with maggots, but failed to rear the adult flies, although it was undoubtedly this species. Fruit of the common guava was scarce, and we made no observations as to their infestation.

Spilonota holotephras Meyrick

This is a small fuscous-colored leafroller moth whose larvae infest the terminal twigs of the common guava. The new leaves are webbed together and eaten before they have expanded. This causes a setback to the growth of the twig and, as there are sufficient caterpillars to seriously check the welfare of the plant, the guava does not thrive well nor become so generally predominant as it does in many regions in Hawaii. This is the same moth which similarly affects the guava in Guam.

Papaya

Dacus xanthodes Broun

This fruitfly was previously reared from papayas, although we had no observations on it at this time. Fruitflies have also been reared from avocadoes in Samoa. There are also other fruitflies in Samoa. Malloch, in the "Insects of Samoa," records seven species altogether as occurring there, none of which is yet known in Hawaii.

Cacao

Hypsipyla swezeyi Tams

The larvae of this phycitid moth feed on seeds in ripened pods. The larvae are white and quite plump, and the moth is gray.

Grasses

Spodoptera mauritia (Boisduval)

Armyworms are quite abundant in places, as evidenced by their egg masses. Thirty egg masses were counted on a small citrus tree in a grassy lawn. There was no evidence of egg parasites. The caterpillars were not numerous in the grass, perhaps due to the large flock of poultry which daily ranged this lawn. At another place, egg masses were more numerous; there were 160 on one leaf of a young royal palm near a golf course. They were mostly old ones, and apparently egg

parasites had issued from most of them, as they had the appearance of *Laphygma* eggs in Hawaii after the parasite *Telenomus nawai* has issued from them. This moth has a wide range of distribution in the tropics. It has been recorded from Hawaii, but it was discovered recently that this record was a misidentification of *Laphygma exempta* (Walker).

Marasmia venilialis (Walker)

This is the same leafroller discussed under corn insects. It feeds on several kinds of grasses.

Marasmia trebiusalis (Walker)

This leafroller is closely related to the above, and is usually found on the grass *Oplismenus compositus*. An *Apanteles* parasite was reared from it.

Cosmopteryx mimeticus Meyrick (Fig. 9)

This pretty little moth is a leafminer in nutgrass (*Cyperus rotundus*), and has a wide range in tropical Africa, India, Australia and South America, and in New Guinea, Fiji and Malaya. It was commonly found in Samoa.

Sogata kirkaldyi (Muir)

Sogata eupompe (Kirkaldy)

Sogata ochrias (Kirkaldy)

Delphacodes dryope (Kirkaldy)

These are four species of delphacid leafhoppers which are abundant in low grasses of the coast, such as Bermuda grass and *Lepturus*(?). Possibly other species of delphacid leafhoppers will be found among our material when fully studied, as well as cicadellid leafhoppers which also occur on grasses.

Phytomyza spicata Malloch

This is the agromyzid leafminer discussed under corn insects as occurring on several kinds of grasses.

The following notes on pests of shade trees and ornamentals may be appropriately appended:

Hibiscus rosa-sinensis

Sylepta derogata (Fab.)

A leafroller moth which is more common on the hau.

Cosmophila flava flava (Fab.)

The moth of a green looper caterpillar, also more common on hau.

Hau (Hibiscus tiliaceus)

Sylepta derogata (Fab.) (Fig. 13)

A medium-size pale-buff moth whose caterpillars are leafrollers. The leaf is cut part way on one side of the midrib, and that portion rolled by several turns into a tube within which the caterpillar hides and feeds. Not abundant. It occurs also

in Africa and Asia, and in Malayan and Australian regions. We found it more abundant in Guam than in Samoa.

Cosmophila flava flava (Fab.)

The green hau looper is a different species than the one in Hawaii. The moth is yellowish-to-ferruginous in coloration. It has about the range of distribution as the preceding. We found it only occasionally in Samoa.

Acrocercops (an undetermined species)

A common leafminer, producing a blotch mine usually near the base of the leaf. An *Apanteles* parasite was reared from it.

Mesohomotoma hibisci (Froggatt)

This is a large green psyllid which occurs in colonies on the new foliage at tips of branches. It occurs in Australia, New Caledonia, Guam, Fiji, and Tahiti. An undetermined lacewing fly and syrphid fly larvae were found feeding on the psyllids, and an undetermined chalcid fly was reared as an internal parasite.

Chrysomelid (undetermined species)

A fairly large-size chrysomelid beetle and its larvae were found feeding in buds of terminal shoots.

CROTON

Aleuroplatus samoanus Laing

This white fly was found very abundant on a croton hedge at one locality.

ERYTHRINA

Othreis fullonia (Clerck)

This large moth has a wide range in tropical Africa, Asia and Australia, and in New Guinea, Fiji, Samoa and Guam. The moth is said to be injurious to fruit. The large black prettily marked caterpillars feed on leaves of *Erythrina*.

Argyroploce rhynchias (Meyrick)

Larvae of a large tortricid moth, which appears to be this species, were found feeding on seeds in pods of *Erythrina,* on the tree. It is related to the moth whose larvae destroy such a large proportion of koa seeds in Hawaii. It is recorded from *Canavalia* seeds in Mauritius and from Ceylon, but not previously in Samoa.

CALOPHYLLUM INOPHYLLUM

Leptynoptera sulfurea Crawford

A delicate psyllid which lives beneath the recurved margins of young leaves of this tree and causes crippled abnormal leaves. It occurs also in Guam and the Moluccas.

TERMINALIA CATAPPA

Thiotricha strophiacma Meyrick (Fig. 14)

This is a minute whitish moth whose larvae feed on the surface of the leaves. Each one cuts out an oval piece of leaf about 7 mm. by 10 mm. which it uses as a shield and moves about from place to place as it feeds beneath it. There may be

2 to 20 of these per leaf. Two leaves with a maximum number had 21 and 25 holes respectively where these shields had been cut out.

Acrocercops(?) (undetermined)

A minute lepidopterous leafminer was found mining the leaves to some extent, but it was not reared.

Adoretus versutus Harold

This is the beetle discussed under corn insects. The beetles feed very extensively on *Terminalia* trees, as evidenced by the abundantly perforated leaves.

Coleus

Psara stultalis (Walker)

A pale light-brown moth with fuscous markings whose caterpillars were quite abundant as leafrollers on Coleus. This moth has a very wide distribution: India, China, Malayan region, Australia, Guam and the Marquesas. It was previously recorded from Samoa. Nothing is given of its feeding habits in the other regions, except that in Guam it was reared from an unidentified plant.

Ageratum conyzoides

Homoeosoma ephestidiella Hampson

This is a small gray phycitid moth whose larvae feed in the flower heads of *Ageratum*. It was quite common and moths were collected from the plant and also reared from the larvae. It was previously recorded from Samoa but no food plant mentioned. It is also known in India.

Spathulina acroleuca Schiner

A pretty little trypetid fly was abundant; it was swept from the plant, and reared from maggots in flower heads where growing seeds were destroyed.

Orchids (Wild Species)

The numerous species of native orchids in the forest were remarkably free from insect attack. However, a few plants were found heavily infested with an undetermined scale insect. Also a few plants were found with leaf miners and some with leafrollers but none reared.

Ferns

Pachyrhabda amianta Meyrick (Fig. 17)

A tiny white moth whose larvae feed on the spores of *Asplenium nidus*, the bird's-nest fern. The larvae feed beneath a flat round disk of webbed-together sporangia and are quite numerous, often dozens of them are seen per frond. An *Apanteles* parasite was often reared from the larvae. This moth is known only in Samoa.

Pachyrhabda antinoma Meyrick

This is another tiny moth whose larvae feed on fern spores of a particular fern (undetermined). The moth has a faint yellowish tinge. The larvae feed beneath

a slight web amongst the sporangia. This moth occurs also in India, East Australia and the Kermadec Islands.

Cossonid weevil (undescribed new species)

A small black cossonid weevil was found very numerous, both larvae and adults, in the living stems of the larger fronds of *Angiopteris evecta* var. *vaupelii* fern. Usually a large proportion of these frond stems were found infested. In case of one large plant, there were only two stems unattacked.

Cranefly (undetermined species)

A cranefly was reared from the living frond stem of an *Aspidium*(?) fern. Nearly all of the stems of this particular fern had been bored lengthwise by the elongate larvae of the cranefly. Transformation took place within the burrow.

Soil Fertility as Affected by Soil Nitrogen

By R. J. Borden

Soil fertility has been defined as "the ability of a soil to produce a crop"; the assumption is, of course, that the environment for the specific crop is satisfactory. When good crop yields have been obtained, the soil fertility has been termed "high," and conversely when the yields were subnormal we have called it "low fertility."

Successful modern agriculture has taken advantage of and applied the findings of its experienced farmers and research men to the end that soils have been made more fertile. This has entailed various modifications in the structural characteristics of the soil profile, with subsequent known adjustments of the soil's air, moisture, and nutrient supply.

In spite of our knowledge and ability to make these adjustments there are still some very elusive factors concerned with soil fertility that we have apparently not controlled. Just what these factors are, we have not definitely proved, but we have our major suspicion which will be revealed as this discussion progresses. Whether or not we can identify, measure, evaluate, and finally find some economical control for these factors is a question that only a considerable amount of new research can answer.

Technique: Our knowledge of factual differences in soil fertility comes largely from our experiences with the growing of various grass crops in pot-culture studies under controlled conditions. The plants in these comparative studies are all grown under equalized exposure, temperature, and sunlight conditions. The source of seed is the same. The same amounts (volume) of soil are used and identical fertilization supplied. Irrigation is adequate and similar, and no leachates are lost. All conditions of environment and culture, except for the variable being studied, are as near alike as we can possibly make them. That we are quite successful in providing identical conditions is shown by the fact that duplicate pots *with the same soil* produce within a given growth period amounts of total dry weight which seldom vary by as much as 10 grams in 200 grams harvested (see Table 1, column headed "Duplicates"). And yet the average yields of dry matter which are harvested *from different soils* may show very significant differences, even after all of these efforts to provide identical conditions.

Seasonal Variation: It is natural to expect, and we do secure, differences in dry weight which are due to the seasonal conditions that exist during a specific cropping period. We have secured an indication of what this difference might be by planting panicum grass in pure silica sand fertilized with identical amounts of complete nutrients, at monthly intervals throughout the year, and harvesting the crop produced after its second 30 days of growth. The following yields of dry matter grown in the respective months indicated, probably represent the effects of the seasonal influences which we did not attempt to control.

PANICUM GRASS GROWN IN SILICA SAND WITH COMPLETE NUTRIENTS AMOUNTS OF DRY MATTER PRODUCED IN DIFFERENT MONTHS

Jan.	100.6 gms.	May	136.4 gms.	Sept.	141.9 gms.
Feb.	93.9 "	June	167.9 "	Oct.	132.1 "
Mar.	100.2 "	July	153.4 "	Nov.	93.0 "
Apr.	108.6 "	Aug.	156.0 "	Dec.	80.0 "

Again, when different amounts of nitrogen were supplied to a crop of panicum grass started in June, the yields that were harvested were considerably larger than those secured from corresponding amounts of nitrogen applied to the same soil for a crop started in December.

The total amounts of nitrogen recovered in the total dry weights harvested were not widely different. Unfortunately root weights and analyses were not secured, but soil analyses after both harvests showed no available nitrogen left in the cropped soil. Apparently the difference in yields between the two series was not due to the amount of nitrogen available, but to a greatly enhanced efficiency of nitrogen during that growth season which followed the June planting.

YIELDS AND NITROGEN RECOVERED IN PANICUM GRASS GROWN ON THE SAME SOIL, BUT FROM CROPS STARTED IN DIFFERENT SEASONS (PROJECT A-105-NO. 104)

Amt. N applied	Series A—Planted in June Harvested at 92 days Dry wt. (gms.)	N in dry wt. (gms.)	Series C—Planted in Dec. Harvested at 94 days Dry wt. (gms.)	N in dry wt. (gms.)
0	47	.113	53	.155
.55 grams	209	.438	159	.446
1.10 grams	282	.903	216	.970
1.65 grams	294	1.265	234	1.286
2.20 grams	329	1.646	228	1.710

Series A—R.C.M. nitrogen in soil at planting=15 p.p.m.
Series C—R.C.M. nitrogen in soil at planting=20 p.p.m.

In still another test we have cropped one of our "stock soils," at 3-month intervals, with panicum grass which had been supplied with identical treatment and growth conditions, and have obtained the following dry weights during a 90-day growth period:

Planted in	Avg. grams of dry wt. harvested Without N	With N (1.1 gms.)
November 1938	19	169
February 1939	24	228
May 1939	31	299
August 1939	39	301

A check on the available nitrogen content of this air-dried "stock soil" during the year's storage has shown it to vary only between 24 and 32 p.p.m., and, since adequate N, P, and K fertilizers were supplied for these crops, it is felt that the results quite clearly indicate the seasonal influences.

If further evidence is desired concerning this seasonal effect upon the amount of total dry matter which can be produced with a specific and similar amount of fertilizer, then a glance at the results in Table I will show that even with slightly longer growing periods the average levels for dry matter harvested from these soils

are progressively less for Groups 1 and 2, and also for Groups 3, 4, and 5, even though identical culture has been given to and within these groups. Thus we are aware of uncontrollable seasonal influences. But when we supply different soils with *the same* growth season, *the same* geographical environment, and with optimum moisture, then fertilize them with phosphate and potash in identical amounts which are also fully adequate for maximum yields, and likewise supply uniform applications of nitrogen, then we must look for another answer to explain the differences in the yields that come from these soils.

TABLE I

YIELDS OF PANICUM GRASS GROWN WITH COMPLETE NUTRIENTS IN MITSCHERLICH POTS WITH DIFFERENT SOILS

Group		Soil	Soil No.	Grams dry wt. harvested: Duplicates	Avg.	S.E.*
Group 1	Planted 8/14/39, Harvested 11/8/39, Age 86 days	H. C. & S. Co. 7B......	3116	215.4, 214.4	214.8	0.4
		Koloa 35	3120	245.5, 251.0	248.3	2.8
		Koloa 8	3118	251.0, 257.9	254.5	3.5
		Waianae 10	3128	267.0, 272.4	269.7	2.7
		Waiakea 13–2	3126	270.2, 275.4	272.8	2.6
		Lihue P–2M	3124	274.8, 271.8	273.3	1.5
		Kaiwiki 35	3122	276.9, 274.6	275.8	1.2
		Grove Farm 23E.......	3130	280.9, 272.9	276.9	4.0
		Grove Farm 12.........	3132	290.5, 285.2	287.9	2.7
Group 2	Planted 9/21/39, Harvested 12/28/39, Age 98 days	Kekaha 303 (3)........	3170	150.6, 158.5	154.6	4.0
		Kekaha 303 (2)........	3168	160.9, 151.5	156.2	4.7
		Wailuku 19	3166	197.7, 197.7	197.7	0
		Maui Ag. 22...........	3160	202.3, 201.5	201.9	0.4
		Lihue 28 Hm...........	3162	212.3, 205.2	208.8	3.6
		Hutchinson 31	3164	232.0, 233.7	232.9	0.9
Group 3	Planted 8/30/39, Harvested 11/22/39, Age 84 days	Waialua Gay 2........	3134	231.0, 237.7	234.4	3.4
		Kemoo 9	3144	240.6, 240.1	240.4	0.3
		Gay 9	3136	243.8, 244.9	244.6	0.6
		Kawailoa 6	3141	283.2, 284.6	283.9	0.7
		Helemano 7B	3139	289.5, 289.3	289.4	0.1
		Kawaihapai 6	3140	302.7, 299.3	301.0	1.7

TABLE I—Continued

YIELDS OF PANICUM GRASS GROWN WITH COMPLETE NUTRIENTS IN MITSCHERLICH POTS WITH DIFFERENT SOILS

			Soil No.	Grams dry wt. harvested Duplicates	Avg.	S.E.*
Group 4	Planted 9/28/39 Harvested 12/28/39 Age 91 days	Waialua Gay 3	3172	203.5 203.5	203.5	0
		Gay 3A	3174	210.4 211.5	211.0	0.6
		Gay 8A	3175	214.0 215.8	214.9	0.9
		Kawaihapai 18	3180	230.4 222.4	226.4	4.0
		Kawaihapai 13	3179	235.5 234.6	235.1	0.5
Group 5	Planted 10/19/39 Harvested 1/26/40 Age 99 days	Waialua Gay 3	3193	165.4 165.9	165.7	0.3
		Kawailoa 14A.	3197	184.6 186.5	185.6	1.0
		Kawaihapai 2B	3199	188.4 186.0	187.2	1.2
		Kawaihapai 4.	3201	200.3 207.1	203.7	3.4
		K'wpai 2B2...	3200	211.5 206.7	209.2	2.4

*Standard error.

Variation in Grass Yields: In Table I, we show data for 5 groups of soils which are a typical cross section of several hundred similar groups that we have studied in connection with our Mitscherlich soil testing. Within each group the results should be strictly comparable, for the panicum grass crops have had the same growth season and identical treatments.

(a) In Group 1, nine soils gathered from widely scattered locations throughout the Islands show significant differences in their fertility when cropped under an identical environment. They have had an adequate supply of water, phosphate, and potash for a maximum crop, and it is not believed that any so-called "minor element" deficiency has existed, although we do not mean to disregard this possibility. Satisfactory conditions for drainage and soil aeration have prevailed. Nitrogen fertilizer has been supplied to all soils alike but not necessarily in an amount sufficient to produce the maximum yield in each soil; hence if the soil itself has been able to supply additional nitrogen from its own natural store, such nitrogen would be a contributing factor to these increased yields. This is just what we believe has happened.

(b) In Group 2, these six very different soils have also produced widely different yields from identically applied treatments. It may be of interest to note that soils Nos. 3170 and 3168 are from virgin cane areas; presumably they have not been able to supply much additional nitrogen from their natural supply.

(*c*) Groups 3, 4, and 5 are all made up from soils taken within a single plantation. They show almost as much differentiation in their ability to produce panicum grass crops under identical conditions as do the soils from the more widely scattered locations represented in Groups 1 and 2.

If still further evidence is needed to support our belief that it is the soil nitrogen supply which dominates this soil fertility picture, then we might present the yields secured from 22 different soils, identically treated and cropped, both (*a*) without added nitrogen fertilizer, and (*b*) with identical amounts of nitrogen. Since phosphate and potash were supplied to all soils alike, in amounts sufficient for maximum yields, the results are apparently the effects of the ability of these different soils to supply nitrogen for their crops (Project A-105—No. 48.017). There is a positive correlation both (*a*) between the yields "with nitrogen" and the yields "without nitrogen" ($r = + .71 \mp .11$), and (*b*) also between the yields "with nitrogen" and the "% available N by R.C.M." ($r = .56 \mp .15$).

TABLE II
GRAMS DRY WEIGHT HARVESTED
(AVERAGES OF 4 POTS)

Pot nos.	Source	Without nitrogen	With 1 gm. nitrogen	% increase for nitrogen	% available N by R.C.M.
1340–43	Waianae	27	328	1,128	.0015
1540–43	Waimanalo	47	356	660	.0040
1536–39	Waialua	50	362	620	.0018
1412–15	Makiki	65	348	438	.0078
1368–71	Puhi	67	352	425	.0030
1348–51	Kahuku	89	378	326	.0035
1388–91	Ookala	104	372	257	.0073
1344–47	Kahuku	127	375	195	.0065
1372–75	Puhi	127	369	190	.0093
1360–63	Puhi	131	378	190	.0088
1352–55	Kahuku	136	387	184	.0088
1380–83	Hamakua	139	386	177	.0060
1376–79	Puhi	139	385	176	.0100
1384–87	Ookala	143	309	116	.0050
1364–67	Puhi	148	396	167	.0090
1404–07	Naalehu	157	390	148	.0118
1396–99	Naalehu	158	387	145	.0060
1392–95	Ookala	176	372	111	.0118
1544–47	Hana	187	416	122	.0070
1408–11	Naalehu	202	406	100	.0128
1356–59	Koloa	215	404	88	.0163
1400–03	Naalehu	223	409	84	.0075

Effects on Sugar Cane: To the sugar man, this discussion will become more pertinent if we can show similar effects on cane from similar inherent differences in soil fertility. Our data are not as extensive and experimental errors are somewhat larger, but nevertheless they are quite convincing.

In Table III, we have the total dry weights of H 109 cane harvested at 12 months from 23 different soils which were cropped under an identical environment and given identical fertilization.

In Table IV, we give the yields of 31–1389 and of D 1135 from 12 different soils which were also identically cropped.

TABLE III

TOTAL DRY WEIGHTS OF H 109 CANE HARVESTED AT 12 MONTHS, AND GROWN WITH IDENTICAL TREATMENT AND ENVIRONMENT ON 23 SOILS (AVERAGES OF 3 POTS)

Identity	Soil No.	Total dry wt. (gms.)	Identity	Soil No.	Total dry wt. (gms.)
Kauai Var. Sta.	25*	653	Ewa—B	15	1,111
Libby—134	19*	678	Kohala—7A	45*	1,128
Manoa—37	1	903	Hamakua—27K	33	1,136
Ewa—19D	17	911	Onomea—64	41	1,139
Hawn. S.—A1-D	27	962	Grove Farm—31C	21	1,186
Hamakua—32K	35	981	Kailua—B	5	1,198
Ham. Var. Sta.	31	991	Kahuku—4 (g)	11	1,274
Kilauea—28D	23*	1,002	Pepeekeo—38	43	1,282
Waipio—Yamada	7*	1,067	Hawn. Agr.—H 23	39	1,331
Ewa—19A	13*	1,073	Kahuku—4 (p)	9	1,335
H. C. & S.—8	29	1,084	Hawn. Agr.—M2-1	37	1,450
Kailua—K	3	1,086			

Difference needed for significance: for odds of 99 to 1 = 172 grams.

*These 6 soils have probably responded to applications of minor elements but, even so, the resultant yields within this group are widely different and indicate some more dominant factor as the cause thereof.

Soil No.	Average dry weights (gms.): Without additional "minor elements"	Average dry weights (gms.): With additional "minor elements"
25	653	765
19	678	785
23	1,002	1,158
7	1,067	1,118
13	1,073	1,143
45	1,128	1,253

TABLE IV

TOTAL DRY WEIGHTS OF 2 CANE VARIETIES* HARVESTED AT 12 MONTHS AND GROWN WITH IDENTICAL TREATMENT AND ENVIRONMENT ON 12 DIFFERENT SOILS (AVERAGES OF 4 POTS)

Source of soil	Soil No.	31–1389 Dry weight (gms.)	D 1135 Dry weight (gms.)
Kihei	H7	850	608
Hakalau	H2	877	1,005
Haleakala	M6	919	760
Kahuku	K12	985	765
Mountain View	O3	1,040	1,019
Helemano	H8	1,122	808
Makiki	M10	1,122	1,051
Makaweli	H4	1,174	1,076
Kapapala	H1	1,177	1,090
Moanalua	H11	1,193	1,082
Waianae	W9	1,252	1,018
Kilauea	K5	1,275	906

Difference needed for significance: for odds of 99 to 1 = 145 grams.

*An analysis of variance suggests a significant interaction between the varieties and the soils; this fact will further complicate our efforts to identify the dominating fertility factors. Thus soils H2 and K5, especially, show widely different effects on the two varieties of cane.

Thus there is real evidence that different soils will also produce differences in cane yields which cannot be explained on the basis of differences in sunlight, temperature, exposure, or of inadequacies in soil moisture or air, or in fertilization with the N, P, and K of commercial fertilizers.

We have already indicated that we suspect that soil nitrogen is the principal factor responsible for the yield differences we have cited. This idea is not new or original but it is apparently one that we have chosen to pay little attention to, for our research has yet to answer many questions that are suggested when we try to list the factors which might affect the supply of available soil nitrogen during the long growing period of a sugar cane crop.

We do not need to discuss herein the need for and the effects of nitrogen fertilization for sugar cane. We know how to recognize nitrogen deficiency and how to correct it, and it is doubtful if we are actually growing any of our cane crops today with an insufficient supply of nitrogen. What we are more concerned with is the avoidance of an excess of nitrogen, because of its detrimental effects on cane quality and the unsound economics it involves. Just one of the results from our controlled skirmish tests will be drawn upon to illustrate this (A-105—No. 126: Treatments Nos. 5 and 6):

AVERAGE YIELD DATA AND ANALYSES SECURED WHEN INADEQUATE, OPTIMUM, OR EXCESSIVE NITROGEN WAS FURNISHED TO 31-1389 CANE HARVESTED AT 12 MONTHS (AVERAGES OF 8 POTS)

Nitrogen applied	Grams per pot	Total dry wt. (gms.)	Lbs. cane	Y % C	Lbs. sugar	% N in juice	% N in leaves*
Inadequate	3	851	3.69	13.48	.48	.012	.94
Optimum	6	1,187	5.21	13.33	.70	.028	1.40
Excessive	9	1,144	4.70	11.41	.54	.067	1.80
Difference needed for significance:							
Odds of 99 to 1......		65	.59	.84	.07	.018	....

*Single sample only.

Thus the use of an excessive amount of nitrogen is clearly shown to be uneconomic.

Many Problems: If we are to use nitrogen fertilizer intelligently we have much to learn. For instance, these questions suggest themselves:

1. What part of the total soil nitrogen supply can be made available? (*a*) When? (*b*) How?

2. Is there a continued replenishment of the available nitrogen supply from this total nitrogen of the soil profile? (*a*) At what rate? (*b*) In what amount?

3. What part of the nitrogen fertilizer that is taken up by the weeds, the soil organisms, and the trash of a current cane crop will be returned and made available for subsequent uptake by this same crop? (*a*) How long will this take? (*b*) Can we speed up the procedure?

4. Is the nitrogen content of the stubble and of the old root system a source of supply for the subsequent crop?

5. What relation exists between the cane tonnage harvested, the root mass and stubble it leaves behind in the soil to decay, and the efficiency of subsequent nitrogen fertilization?

6. How may differences in field practices, which result in different amounts of unburned trash being left on a ratoon field, influence the results from a specific nitrogen application?

7. Can the available nitrogen supply in the soil of a field that is being cropped continually with sugar cane be "built-up" by nitrogen fertilization in the same manner that the soil phosphate supply can be permanently increased?

Perhaps one major question is all that is needed to suggest these same problems, *i.e.*, "How does the soil organic matter affect the results which are expected when we fertilize sugar cane soils with nitrogen?" for it is at once apparent that all of these questions suggest a relationship between nitrogen and the soil organic matter, and that the answers are those which will come largely from the researches of the soil biologist, for we believe that it is the number, nature, and seasonal activities of the soil microorganisms under the constantly changing conditions which we artificially create through our various cultural and fertilizer and irrigation practices, that hold the key to the correct answers.

Unfortunately we have made few studies of this biological activity in our soil fertility research. But we do have considerable evidence, that has been obtained by measuring the effects from known additions of nitrogen and organic materials to soils, that in itself suggests the influence of soil microorganisms, and indicate how difficult it is to predict expected results from a specific nitrogen fertilizer application without knowledge of the expected response from the soil population.

An accompanying photograph (Fig. 1) from Project A-105—No. 136 shows at 8 and at 16 weeks comparative growth of 31–1389 cane on 5 soils, which when potted had the following amounts of available nitrogen: left to right 8, 39, 63, 82, and 101 p.p.m. No additional nitrogen fertilizer has been supplied, and there is an excellent agreement between the original content of available soil nitrogen and the yields.

We noted somewhat similar evidence while studying the relation between panicum grass yields and available soil N in Table II.

However, our final agreement is not always as good as this. We can show some weaknesses in this agreement for the results in Tables I, III, and IV. For example, when we arrange the average dry weights harvested from the "complete fertilizer" series in an ascending order of values and set against these values certain other measurements, we can by inspection alone see the absence of a good correlation with the available (?) nitrogen supply, as measured by our R.C.M. and Mitscherlich tools (see Table V). Apparently our designation of "available" nitrogen is somewhat incomplete and in some instances it may be of questionable use in enabling us to determine the amount of nitrogen which the cane crop can be expected to pick up during its long growth period.

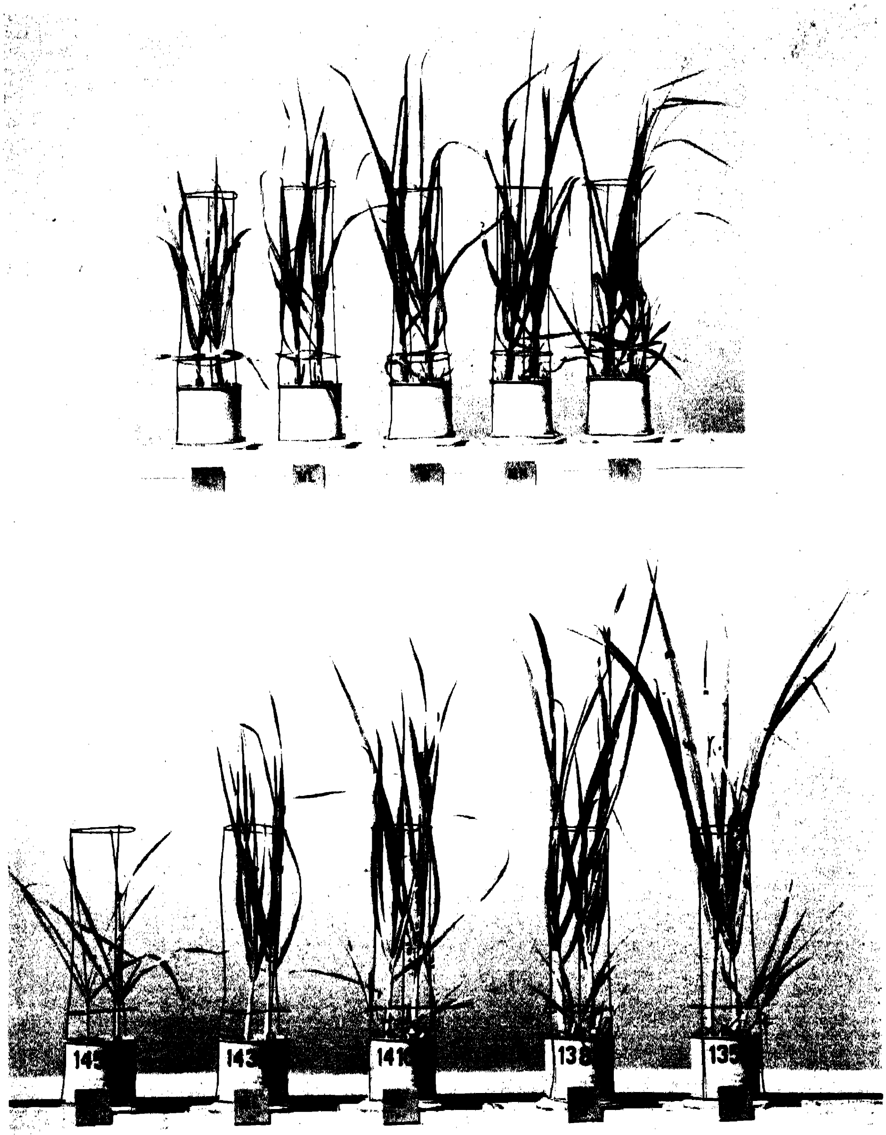


Fig. 1

Comparative growth of 31–1389 cane on 5 different soils. Upper: at 8 weeks; lower: at 16 weeks.

Soil	p.p.m. N at potting	Grams dry weight produced at 8 weeks	Grams dry weight produced at 16 weeks
L	8	15.6	21.4
ML	39	25.2	40.3
M	63	28.7	63.4
MH	82	34.2	84.6
H	101	33.9	99.6

TABLE V

SOME RELATIONS BETWEEN YIELDS AND AVAILABLE NITROGEN IN SOIL AT PLANTING, WITHIN EACH OF 5 GROUPS OF SOILS

(*a*) Data associated with panicum grass yields from Table I.

	No.	Avg. dry wt. with complete fertilizer	Avg. dry wt. without N	Nitrogen in soil at planting p.p.m. by R.C.M.	Nitrogen in soil at planting lbs. per acre by Mitscherlich test
Group 1	3116	214.8	32.0	40	73
	3120	248.3	78.6	43	175
	3118	254.5	40.0	28	81
	3128	269.7	55.3	96	119
	3126	272.8	165.6	85	200
	3124	273.3	74.3	36	149
	3122	275.8	53.1	38	97
	3130	276.9	44.7	63	84
	3132	287.9	75.0	68	141
Group 2	3170	154.6	40.6	28	138
	3168	156.2	39.0	35	129
	3166	197.7	63.9	35	193
	3160	201.9	47.2	61	128
	3162	208.8	58.6	63	162
	3164	232.9	50.5	80	131
Group 3	3134	234.4	38.5	28	85
	3144	240.4	53.8	73	120
	3136	244.6	38.1	26	78
	3141	283.9	45.3	26	92
	3139	289.4	53.6	33	98
	3140	301.0	47.2	28	74
Group 4	3172	203.5	35.5	15	86
	3174	211.0	43.0	25	110
	3175	214.9	46.2	33	116
	3180	226.4	47.7	38	102
	3179	235.1	45.9	35	93
Group 5	3193	165.7	19.0	23	57
	3197	185.6	32.3	45	94
	3199	187.2	22.3	23	58
	3201	203.7	35.6	30	93
	3200	209.2	34.6	28	84

TABLE V—Continued

SOME RELATIONS BETWEEN YIELDS AND AVAILABLE NITROGEN IN SOIL AT PLANTING, WITHIN EACH OF 5 GROUPS OF SOILS

(*b*) Data associated with cane yields from Tables III and IV.

Cane var.	Soil No.	Dry weight harvested (gms.)	p.p.m. available N by R.C.M.	Cane var.	Soil No.	Dry weight harvested (gms.)	p.p.m. available N by R.C.M.
H 109	25	653	8	31–1389	H7	850	53
	19	678	16		H2	877	12
	1	903	8		M6	919	18
	17	911	8		K12	985	9
	27	962	16		O3	1,040	17
	35	981	16		H8	1,122	63
	31	991	15		M10	1,122	18
	23	1,002	14		H4	1,174	11
	7	1,067	20		H1	1,177	25
	13	1,073	14		H11	1,193	13
	29	1,084	7		W9	1,252	6
	3	1,086	8		K5	1,275	115
	15	1,111	16				
	45	1,128	24	D 1135	H7	608	53
	33	1,136	20		M6	760	18
	41	1,139	28		K12	765	9
	21	1,186	43		H8	808	63
	5	1,198	16		K5	906	115
	11	1,274	23		H2	1,005	12
	43	1,282	37		W9	1,018	6
	39	1,331	18		O3	1,019	17
	9	1,335	50		M10	1,051	18
	37	1,450	26		H4	1,076	11
					H11	1,082	13
					H1	1,090	25

The Search for Facts: With such a background of information, the premise we held was to the effect that the soil microorganisms were in control of soil nitrogen availability. Being without the necessary experience and equipment to measure this microorganic content and its activity directly, we proposed a skirmish test (Project A-105—No. 46.4) that we hoped would measure its effects by securing frequent samples for analyses of the available (R.C.M.) nitrogen content of uncropped soils to which varying amounts of nitrogen fertilizer and organic matter were to be added, and which were to be given optimum conditions to encourage the maximum activity of the desirable soil organisms.

Two soils which we have previously studied quite extensively were selected. These may be briefly described as follows:

Characteristics	Manoa soil	Makiki soil
Elevation	550 ft.	40 ft.
Origin	Residual	Alluvium
Color	Yellow brown	Dull gray brown
Texture	Light clay loam	Silty clay loam
Structure	Crumb	Nut
Consistence	Loose and friable	Plastic and sticky
Volume weight	.85	1.05
Phosphate fixation index	90	35
pH	5.4	7.2
% available N	.0024	.0015
% available P_2O_5	.014	.032 +
% available K_2O	.003 —	.018
% available CaO	.009 —	.62

We supplied adequate phosphate and potash to both soils at time of potting. Commercial nitrogen fertilizer was used at the rates of 300 and 600 pounds of N per acre (surface area). Filter cake at rates of 33 and 66 tons (wet basis) per acre provided a readily decomposable source of organic matter, and at these rates furnished equivalent amounts of nitrogen (300 and 600 pounds respectively) as were used in the commercial fertilizer.

The two soils were air-dried, screened, and thoroughly mixed before being placed in standard Mitscherlich pots. After potting, all containers were placed on flat cars which could be run into a covered greenhouse at night and during periods of rainy weather. During the 70 consecutive weeks which our analyses covered, all pots were kept moist, were protected from loss of nutrients through leaching, and were similarly exposed to direct sunlight except when greenhouse protection was necessary. Periodically, once or twice a month, the soil of every pot was removed, remixed, and returned; this should have provided adequate aeration. Hence with such conditions of moisture, temperature, and aeration, we should have had very satisfactory microorganic activity in these two soils.

The total number of pots with each soil was thereafter divided to provide for 8 treatments in each of 4 series. These treatments were as follows:

No.	Additions of— Filter cake	Fertilizer nitrogen
1	None	None
2	At 33 tons/acre	None
3	At 66 tons/acre	None
4	At 33 tons/acre	At 300 lbs./acre from ammonium nitrate
4a	At 33 tons/acre	At 300 lbs./acre from ammonium sulphate
4b	At 33 tons/acre	At 300 lbs./acre from nitrate of soda
5	None	At 600 lbs./acre from ammonium nitrate
6	None	At 300 lbs./acre from ammonium nitrate

These additions were not mixed into the soils in their respective containers until the specific dates which were scheduled for the starting of each of the 4 series; this was done so that different seasonal effects might exert their influences. Thus the 4 series were started as follows: Series I in August, Series II in October, Series III in February, and Series IV in April.

From each treatment in each series a soil sample was taken after the series was started, and thereafter at intervals of 2 weeks an additional soil sample was taken. The samples were generally analyzed* for their available ammoniacal and nitrate

*Full credit for R.C.M. nitrogen analyses is acknowledged to H. M. Lee, and for sampling and general conduct of test to A. Y. Ching.

nitrogen content within a week from the time they were taken. Consecutive samples were taken during an elapsed period of 70 weeks for each series.

TABLE VI

TREATMENT NO. 1—CONTROLS (NO SUPPLEMENTS OF FILTER CAKE OR NITROGEN FERTILIZER); P.P.M. AVAILABLE NITROGEN IN SOIL SAMPLES TAKEN AT 2-WEEK INTERVALS

	Manoa soil				Makiki soil			
Month	Ser. I	Ser. II	Ser. III	Ser. IV	Ser. I	Ser. II	Ser. III	Ser. IV
1937—Aug.	24	(24)	(24)	(24)	15	(15)	(15)	(15)
Aug.	48	*	*	*	12	*	*	*
Aug.	33	*	*	*	13	*	*	*
Sept.	44	*	*	*	20	*	*	*
Sept.	45	*	*	*	15	*	*	*
Oct.	30	*	*	*	18	*	*	*
Oct.	45	42	*	*	27	17	*	*
Nov.	45	50	*	*	20	17	*	*
Nov.	50	32	*	*	28	17	*	*
Dec.	60	60	*	*	40	32	*	*
Dec.	45	45	*	*	25	16	*	*
1938—Jan.	60	45	*	*	60	25	*	*
Jan.	60	47	*	*	20	30	*	*
Jan.	..	..	*	*	..	..	*	*
Feb.	70	60	50	*	22	42	22	*
Feb.	80	75	55	*	35	40	30	*
Mar.	70	60	50	*	40	40	35	*
Mar.	75	70	70	*	50	45	50	*
Apr.	75	75	70	*	50	40	55	*
Apr.	90	75	75	70	42	40	18	30
May	102	90	90	80	42	30	40	40
May	100	100	100	80	35	40	45	30
June	120	120	100	90	45	45	45	43
June	140	130	125	100	50	50	50	50
July	150	120	120	100	35	30	40	45
July	126	126	100	100	30	40	45	40
July	130	140	132	130	35	45	50	50
Aug.	124	153	134	100	35	50	45	50
Aug.	136	143	154	134	45	55	50	50
Sept.	126	142	152	154	40	45	45	45
Sept.	126	146	154	144	45	50	45	40
Oct.	112	116	129	103	45	50	45	55
Oct.	130	140	130	132	50	50	50	50
Nov.	152	158	156	156	50	45	52	50
Nov.	128	156	142	133	45	50	58	50
Dec.	134	138	146	126	50	50	53	45
Dec.		164	164	152		56	49	56
Dec.		156	156	136		42	52	50
1939—Jan.		168	135	126		65	68	63
Jan.		162	157	136		73	72	68
Feb.		128	123	102		27	52	60
Feb.		123	145	118		19	23	52

TABLE VI—Continued

TREATMENT NO. 1—CONTROLS (NO SUPPLEMENTS OF FILTER CAKE OR NITROGEN FERTILIZER); P.P.M. AVAILABLE NITROGEN IN SOIL SAMPLES TAKEN AT 2-WEEK INTERVALS

	Manoa soil				Makiki soil			
Month	Ser. I	Ser. II	Ser. III	Ser. IV	Ser. I	Ser. II	Ser. III	Ser. IV
Mar.			154	130			52	62
Mar.			156	148			57	52
Apr.			148	106			30	54
Apr.			160	158			55	57
May			129	94			35	55
May			128	140			35	50
June			138	106			30	60
June			132	132			32	59
			—				—	
July				128				58
July				116				52
July				110				48
Aug.				101				58
Aug.				98				64
				—				—

*Not actually sampled but given the same attention and conditions, and hence were duplicates of Series I.

In Table VI we have recorded the available nitrogen content as it was found from the analyses made on consecutive samples taken from both of the "control" soils, *i.e.*, the untreated soils or Treatment No. 1, in each series. These data show a very definite increase in the available nitrogen supply which resulted when these soils, without supplements of anything other than air, water, and sunlight, were given good conditions for microorganic activity. Of special interest is the evidence of the variation in the available nitrogen content, for although the trend is certainly one which shows that an increased nitrogen content follows an increase in time from date of potting field soils, yet the consecutive samplings from the same pots of soil (*i.e.*, within any one series) sometimes show some rather surprisingly abrupt increases or decreases. We do not feel warranted in attributing any great amount of this difference to the sampling or analytical errors, but believe it to be an actual fluctuation that was controlled by the soil organisms. We believe that the rather small range in the variation of this relatively elusive available nitrogen between the four duplicates of each soil, at any single sampling period between April and November 1938, indicates considerable uniformity in the microorganic activity at any one period of time. We have considerable confidence that the sampling and analytical techniques were quite satisfactory. As a check on these techniques, we have the results of many analyses that have been made from duplicate, uncropped pots of different soil treatments taken from other studies, and these show rather close agreements between the duplicates. Here are just a few typical examples of the close agreement between duplicate pots (*"a"* and *"b"*), and the differences between such duplicates probably indicates the extent of the sampling and analytical errors in our present study:

No.	% NH_3 nitrogen	% NO_3 nitrogen	p.p.m. available nitrogen	No.	% NH_3 nitrogen	% NO_3 nitrogen	p.p.m. available nitrogen
1*a*	.0042	.0050	92	6*a*	.0005	.0027	32
b	.0042	.0045	87	*b*	.0003	.0020	23
2*a*	.0035	.0060	95	7*a*	.0002	.0045	47
b	.0040	.0050	90	*b*	.0002	.0055	57
3*a*	.0003	.0175	178	8*a*	.0003	.0024	27
b	.0003	.0160	163	*b*	.0002	.0030	32
4*a*	.0040	.0070	110	9*a*	.0002	.0045	47
b	.0040	.0080	120	*b*	.0002	.0025	27
5*a*	.0060	.0080	140	10*a*	.0010	.0022	32
b	.0055	.0080	135	*b*	.0010	.0022	32

The analytical data are voluminous and hence need simple graphical presentation for clear comprehension. Variations in the amounts of available nitrogen which were found in consecutive samples have made it advisable to present the data on a basis of running averages for 3 consecutive analyses rather than to attempt to plot the analyses of single samples. (One exception is presented in Figs. 8 and 9 which are purposely introduced for comparison with Figs. 6 and 7.) Finally, figures for ammoniacal and nitrate nitrogen have been combined and are presented as total p.p.m. available nitrogen, except in Fig. 17 where the progress of nitrification of ammonium sulphate is shown.

We turn then to a study of the graphs.

Figs. 2 and 3: Series I was started in August. The difference in the available nitrogen levels of the two soils without additional nitrogen fertilizer or filter cake (Treatment No. 1) is striking. Although this difference was not very great at the time the two soils were potted, it became increasingly greater with time. In April when the Makiki soil had reached its peak amount, the available nitrogen in the Manoa soil was still increasing, and in July this Manoa soil had increased its available nitrogen by well over 100 p.p.m. more than it started with.

When nitrogen fertilizer was supplied without filter cake (Treatment No. 6) the effect on the available nitrogen of the two soils was quite dissimilar. On the Manoa soil, there was an immediate and definite increase during a period of 8 weeks in August and September followed by a corresponding drop through October, November and December, and then a sharp rise which continued and reached a peak in midsummer; thereafter in September and October it again fell off. On the Makiki soil the corresponding treatment (No. 6) immediately showed a drop in its nitrogen content which continued through November and then started to rise, reaching its peak with considerably more irregularity than the Manoa soil at about the same time in midsummer, thereafter dropping off both a little faster and a little sharper. Whereas the Manoa soil apparently had a greater available N content at the end than at the start of this study, the Makiki soil had quite definitely locked up or lost some of the soluble nitrogen fertilizer which it had received.

With the increase in soil organic matter which resulted when filter cake was added to these soils, we note an immediate drop in the available nitrogen content. For a few weeks after this material was incorporated with the soil the total available nitrogen content was almost nil when no nitrogen fertilizer had been supplied (Treatment No. 2) but thereafter it began to "come back." After approximately 30 weeks on the Manoa soil, it caught up with and then produced more nitrogen than

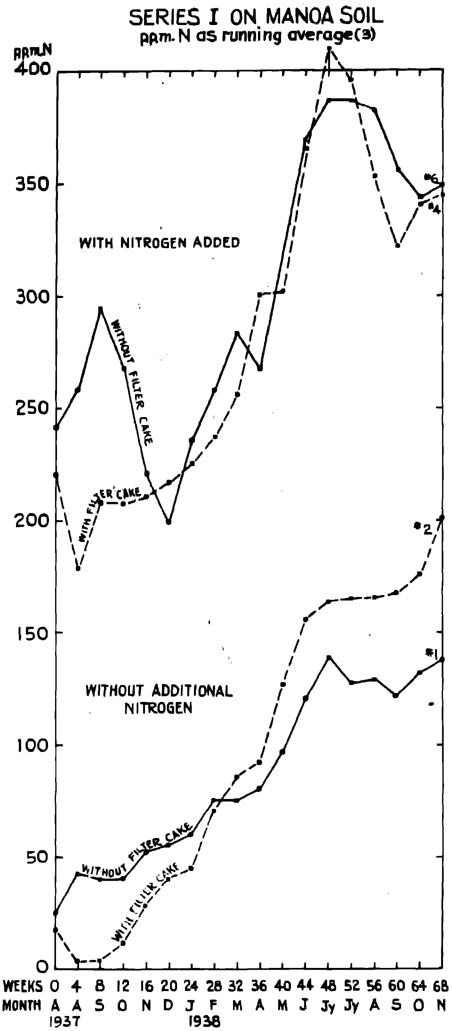


Fig. 2

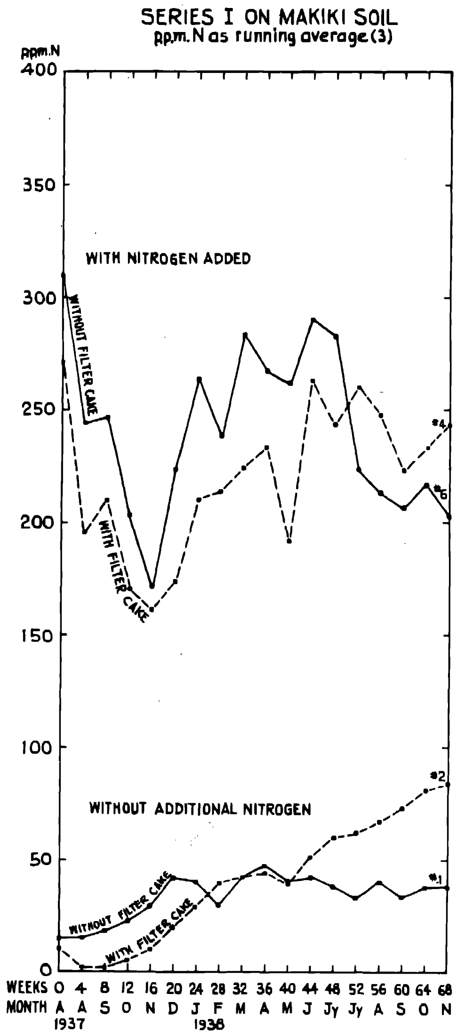


Fig. 3

the corresponding soil which had not had the filter cake. On the Makiki soil, a similar action occurred but it was somewhat slower and some 40 weeks had elapsed before it had produced more nitrogen than its control. At the end of 70 weeks both soils had recovered about the same amounts of nitrogen from that supplied as a constituent of their respective filter cake additions.

When nitrogen fertilizer was also supplied with the filter cake (Treatment No. 4), the issue is not as clear as when no extra nitrogen was given. On the Manoa soil it is doubtful if the nitrogen content of the filter cake contributed anything to the available supply; on the Makiki soil it most certainly did not do so for a whole year, and the indication of a small increase thereafter is perhaps not highly significant. Hence it would appear that when this filter cake was used with the additional nitrogen fertilizer, it contributed very little available nitrogen to these soils within a period of 70 weeks.

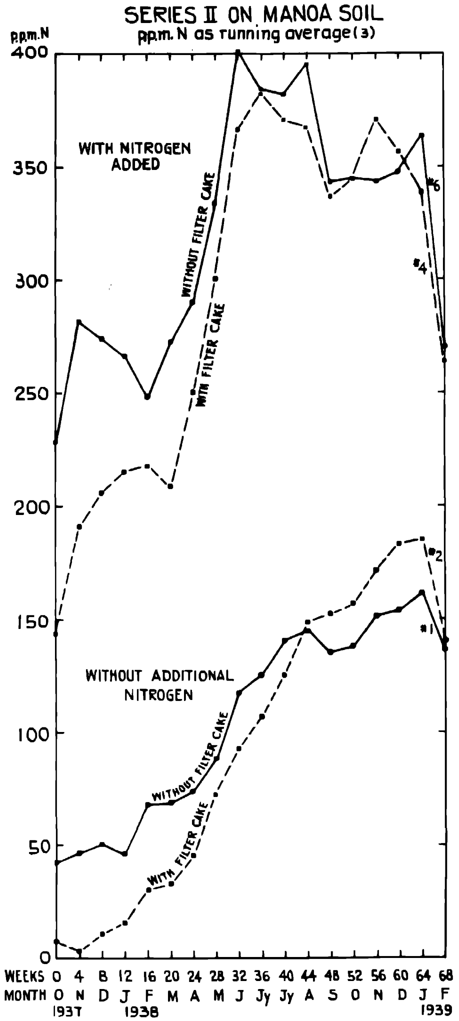


Fig. 4

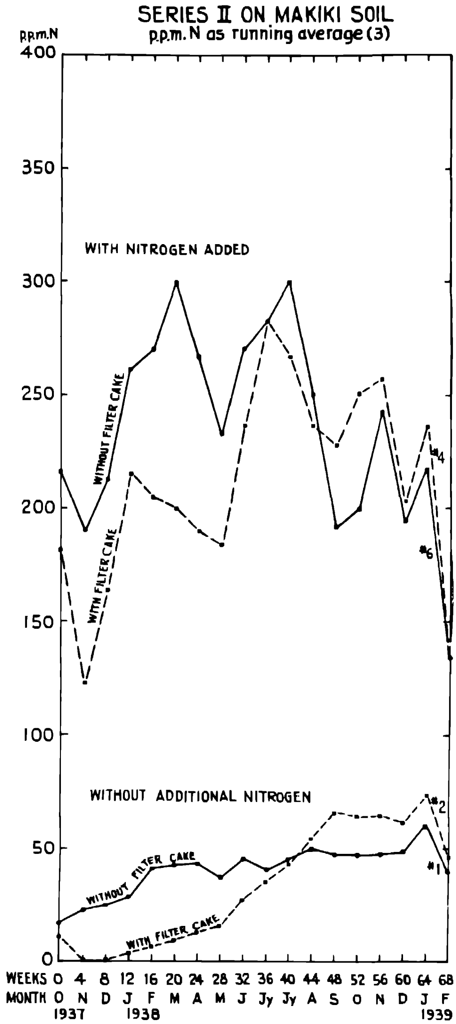


Fig. 5

Figs. 4 and 5: Series II was started in October. The picture shown in Figs. 4 and 5 is not entirely unlike that in Figs. 2 and 3 which we have just discussed. We note the same higher level of available nitrogen in the Manoa soil and its steady increase during the warm summer months, which is again in contrast to the relatively constant supply of nitrogen in the Makiki soil during this same time. We also note the immediate rise, fall, rise, and fall of Treatment No. 6 on the Manoa soil, and the corresponding immediate drop, rise, and gradual falling off again of the nitrogen in the Makiki soil without filter cake.

We find the same rapid depression in the available nitrogen content that follows the addition of the filter cake in both soils, but in this Series II, the nitrogen that is tied up by the filter cake in the Manoa soil is apparently not released until nearly a year later, and thereafter does not contribute as definitely to the total available supply as it did in Series I. Likewise on the Makiki soil the filter cake has apparently not contributed some of its nitrogen as definitely as it did in Series I on this same soil.

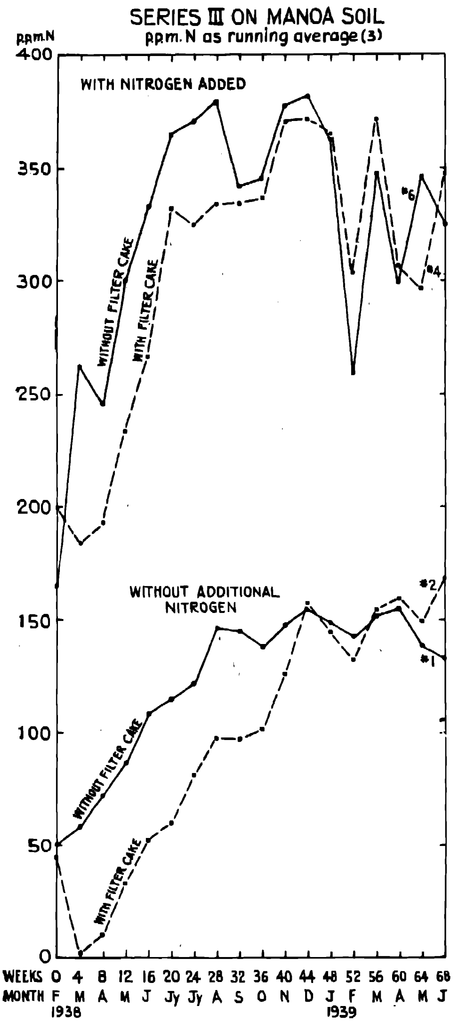


Fig. 6

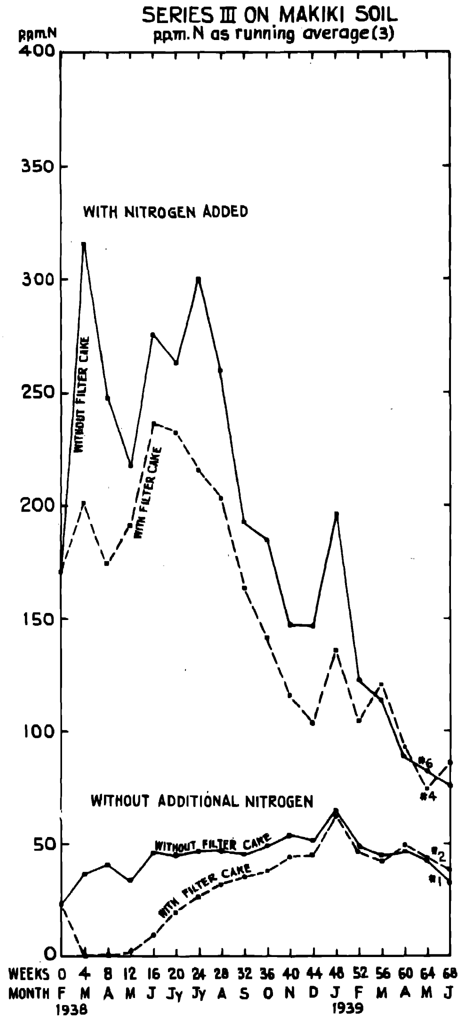
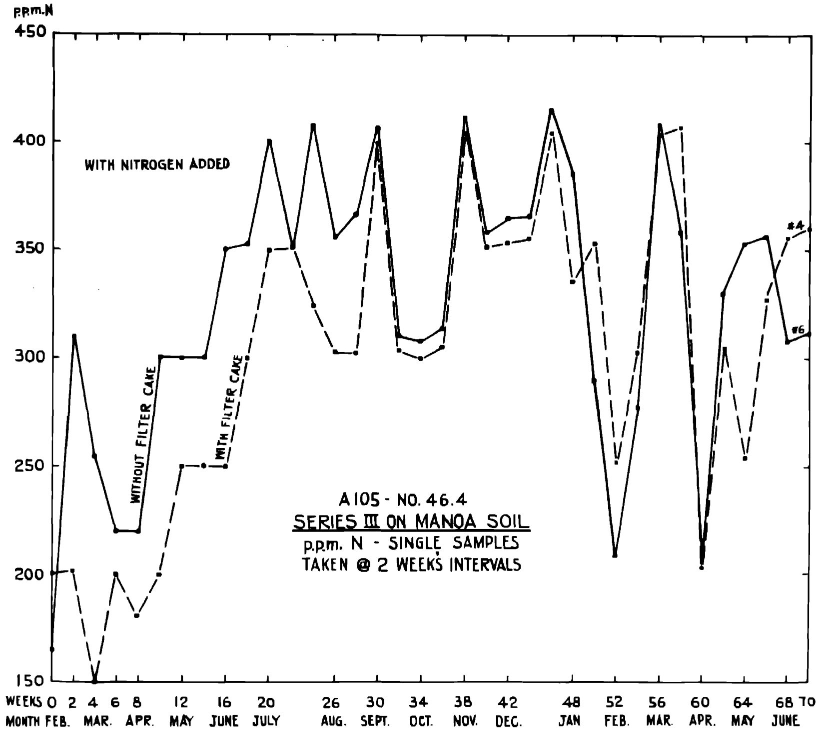


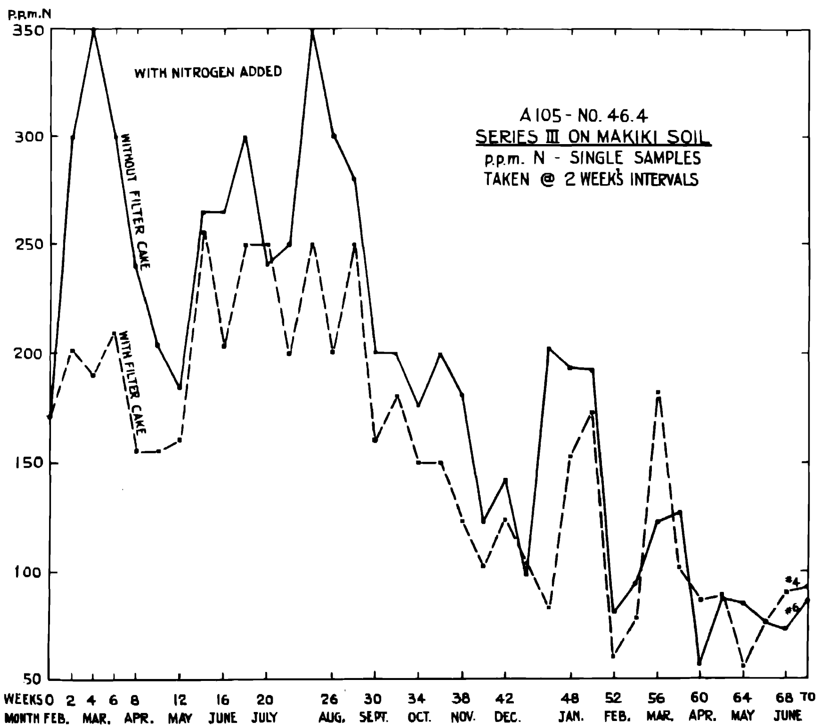
Fig. 7

Used with nitrogen fertilizer, the filter cake additions to both soils show negligible, if any, contribution to the total available nitrogen supplies therein.

Figs. 6 and 7: Series III was started in February. The graphs in Fig. 6 are quite similar to those in Fig. 4, and those for Treatments 1 and 2 in Fig. 7 are not unlike the corresponding ones in Fig. 5. The results would indicate that during the 70-week testing period, the available nitrogen levels have been reduced where this kind of organic material was added and, that even at the end of this period, there has been no real increase from the 300 pounds per acre application of the nitrogen from the filter cake.

In one respect, the graphs for Treatments 4 and 6 in Fig. 7 are quite different from their counterparts in Figs. 3 or 5; *i.e.*, the distinct and continuous loss of available nitrogen when nitrogen fertilizer was added to this Makiki soil both with and without filter cake. We are completely at a loss to explain this occurrence; we have been unable to find any errors or changes in cultural conditions, or in our


p.p.m.N
450
400
350
300
250
200
150
WITH NITROGEN ADDED
WITHOUT FILTER CAKE
WITH FILTER CAKE
A105 - NO. 46.4
SERIES III ON MANOA SOIL
p.p.m. N - SINGLE SAMPLES
TAKEN @ 2 WEEKS INTERVALS
#4
#6
WEEKS 0 2 4 6 8 12 16 20 26 30 34 38 42 48 52 56 60 64 68 TO
MONTH FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC. JAN FEB. MAR. APR. MAY JUNE


P.P.m.N
350
300
250
200
150
100
50
WITH NITROGEN ADDED
WITHOUT FILTER CAKE
WITH FILTER CAKE
A105 - NO. 46.4
SERIES III ON MAKIKI SOIL
p.p.m. N - SINGLE SAMPLES
TAKEN @ 2 WEEKS INTERVALS
#4
#6
WEEKS 0 2 4 6 8 12 16 20 26 30 34 38 42 48 52 56 60 64 68 TO
MONTH FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY JUNE

Figs. 8 and 9

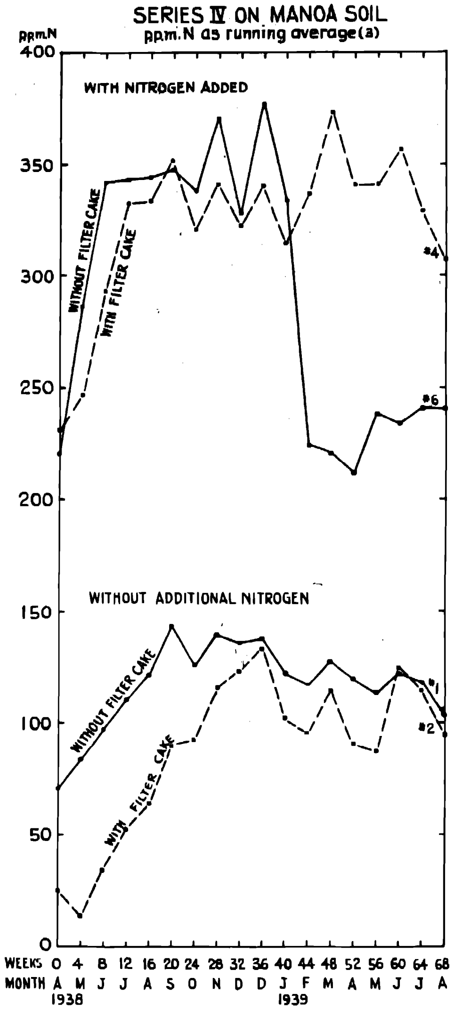


Fig. 10

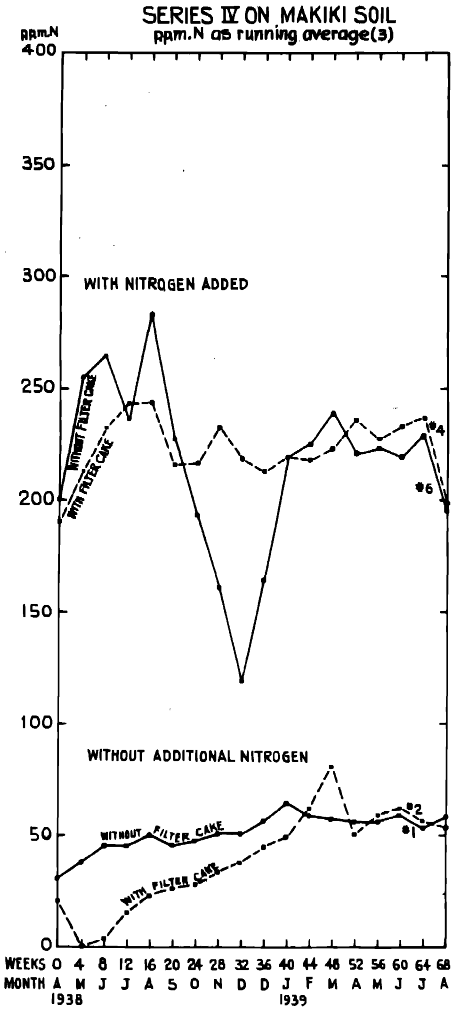


Fig. 11

sampling or analytical techniques that would indicate the data to be other than an accurate measurement of the available nitrogen that was actually present in this soil when it was sampled.

Figs. 8 and 9: Series III. These two graphs are made up from the separate analyses of the single samples taken at 2-week intervals from Treatments 4 and 6 on both soils in Series III. The same data are presented for 4-week intervals as running averages of 3 consecutive samplings in Figs. 6 and 7 and so have already been discussed.

Figs. 10 and 11: Series IV started in April. The graphs in Figs. 10 and 11 lend further support to what has already been so aptly shown, *i.e.,* (*a*) the depressing effect from applications of filter cake upon the available nitrogen supply of both soils; (*b*) the very small contribution which the nitrogen content of the filter cake actually makes to the soil supply within 70 weeks; (*c*) the unexplainable variations in the available nitrogen supply of soils, especially when nitrogen fertilizer has been added; and (*d*) the differences in the ultimate levels of available nitrogen and of the rates of increase in different soils.

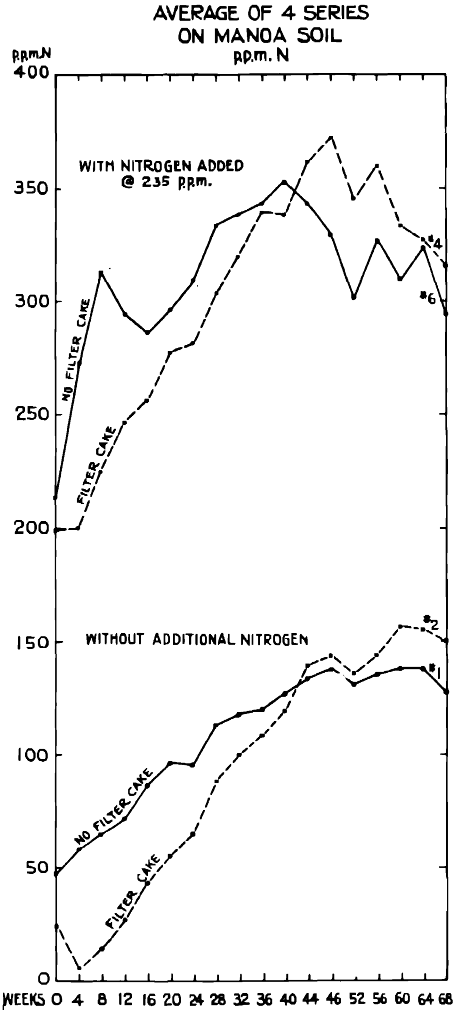


Fig. 12

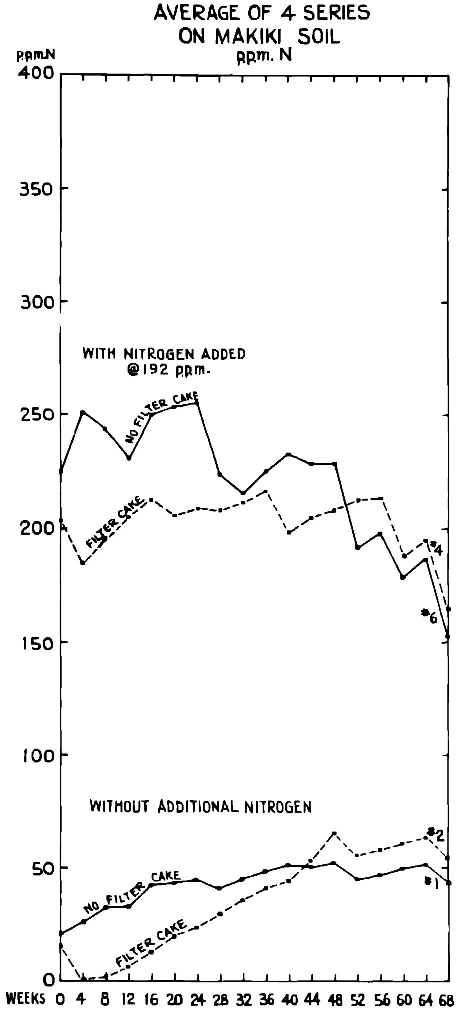


Fig. 13

The drop in the nitrogen content of Treatment No. 6 of this series on the Manoa soil in February 1939 may be in some way related to its higher moisture content. The soil sample when taken was saturated with water which unfortunately had come from a leak in the glass roof during a rain. The apparent permanency of this lower nitrogen content is hard to explain, however, since the excess water had all been caught in the drainage pan under the pot and was subsequently returned to the soil. Furthermore, the adjacent and comparable pot with Makiki soil which was also wet through the same cause did not show any loss of nitrogen. Thus for a period of only a few weeks this Manoa soil was somewhat wetter than usual.

Figs. 12 and 13: Averages of all 4 series. In these two figures we show the composite picture of the 4 treatments on both soils which we have shown as individual series in the foregoing graphs. Hence, disregarding seasonal effects, which under the conditions of our study are insignificant in comparison with the effects of the elapsed time intervals after the treatment applications, Figs. 12 and 13 tell a

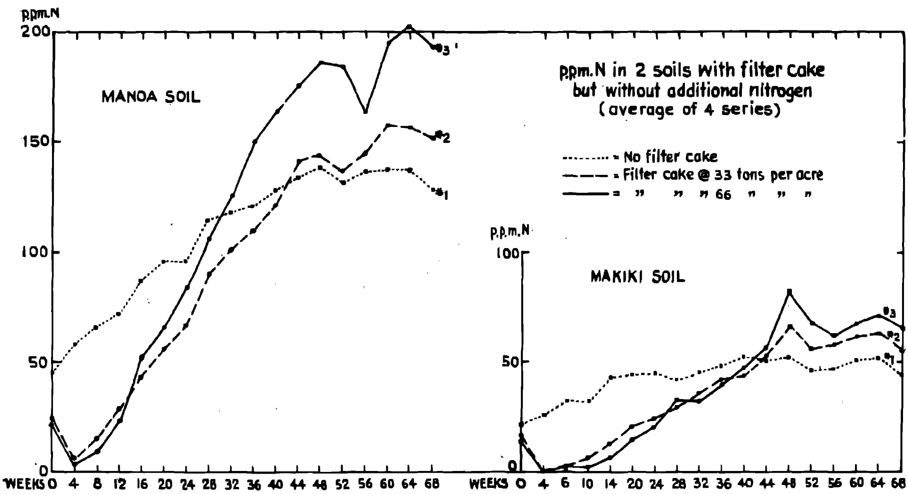


Fig. 14

story which has its practical significance. For instance, even when optimum conditions are provided for the maximum activity of soil microorganisms, the incorporation in a soil of an organic material like filter cake with its wide ratio of carbon-to-nitrogen will reduce the normal amount of available soil nitrogen for approximately a year thereafter. Hence the return of this nitrogen which has been tied up in this way by the microorganisms, together with the probable release of a very small part of the nitrogen originally carried by the organic matter itself, may come so late in the growth of a crop of sugar cane that it will probably have the same effect as a late application of nitrogen, *i.e.*, it will produce more cane with a poorer quality at harvest.

Periodic, unexplainable variations in the available nitrogen supply of different soils, following an initial application of nitrogen fertilizer, indicate that similar variations may be expected to occur each time that nitrogen fertilizer is applied to the growing crop. It is further surmised that the more slowly decomposable soil organic materials will likewise affect this variation when later nitrogen applications are made. Such conditions will undoubtedly have their corresponding influence upon the amount of nitrogen that would be available for absorption by a growing crop.

Fig. 14: To more clearly compare the differences between the two soils to which filter cake but no additional nitrogen fertilizer had been added, we present Fig. 14. The depression in the available soil nitrogen was of slightly shorter duration on the Manoa soil where the heavier amount of filter cake was concerned, but with the smaller (33-ton) application both soils were below the controls (Treatment No. 1) for 44 weeks.

At the end of 70 weeks the corresponding amounts of nitrogen finally contributed by the filter cake to the Manoa soil were more than double those to the Makiki soil. However, it is doubtful if this greater contribution to the Manoa soil amounts to more than about 25 per cent of the total nitrogen content of the filter cake which was originally applied.

Fig. 15: The data shown on this graph, No. 15, are from the soils which had not received any filter cake, but which had been supplied with different amounts of nitrogen fertilizer.

Without nitrogen fertilization the Makiki soil shows only minor fluctuations in its available soil nitrogen content during the entire period of 70 weeks. Such nitrogen content is less than half the total found in the corresponding treatment on the Manoa soil, which in the same period has increased its available nitrogen supply by about 100 p.p.m.

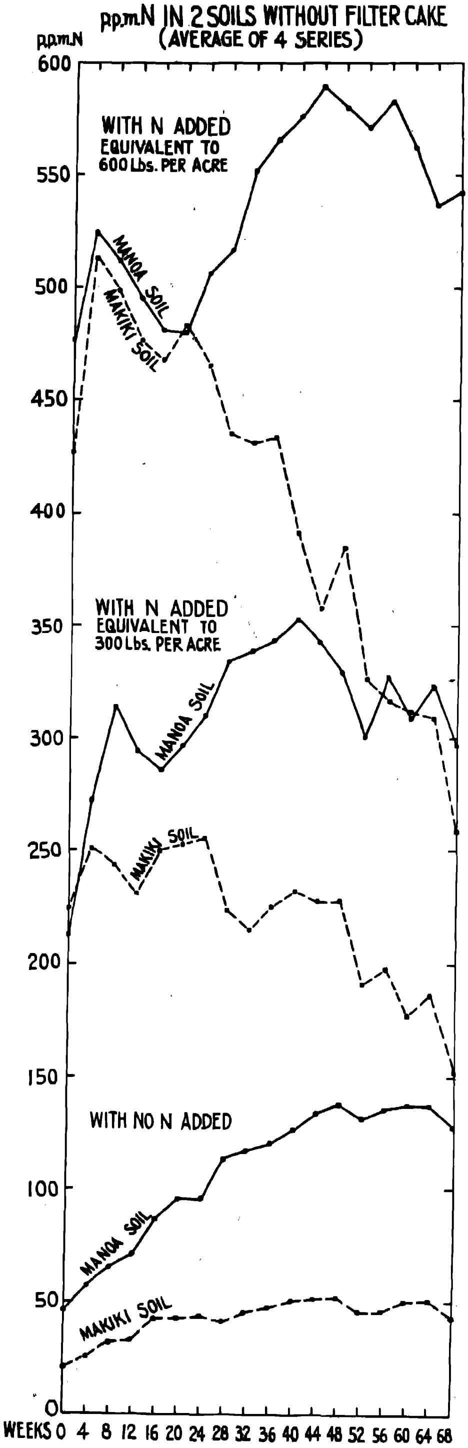
With nitrogen fertilizer applications equivalent to 300 pounds per acre, the picture is changed. The variations in both soils throughout the 70-week period are considerably greater and in the case of the Makiki soil there is a definite loss of available nitrogen. Thus the difference in nitrogen content between these two soils is shown to be increasingly greater with time.

This is more strikingly shown when the nitrogen fertilization was equivalent to 600 pounds per acre, and here the continued loss of available nitrogen from the Makiki soil needs a real explanation which we are unable to provide.

Fig. 16: A supplementary study, wherein both ammonium sulphate and nitrate of soda were compared with the ammonium nitrate we have used in the treatments previously discussed, shows the great similarity of effects from all three nitrogen carriers when used in addition to filter cake on both soils. Such differences in the amounts of available soil nitrogen as were measured between the different sources of nitrogen are probably not greater than would occur by chance alone.

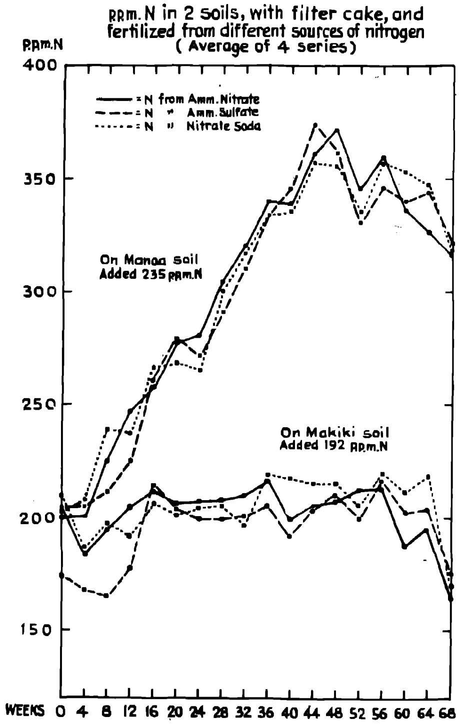
Fig 17: The data shown in Fig. 17 indicate the rapidity with which ammonium sulphate was nitrified by these soils under the favorable conditions that were provided. On the Manoa soil the ammonia was completely nitrified within a period of ten weeks; on the Makiki soil under the same conditions, it required sixteen weeks to completely nitrify the ammoniacal nitrogen. Thus we have vivid evidence of beneficial microorganic activity in these soils.

Conclusion: It is quite apparent from the data presented herein that soil fertility includes something else besides N, P, and K. It is our feeling that this "something else" is largely the relationship between the soil organic matter and its rate of decomposition. This organic matter may have been produced "in place" or it may have come from outside sources. Its rate of decomposition will be governed largely by the number and kinds of microorganisms, and their abundance and activities will be under the influence of the soil's structure, aeration, moisture, temperature, reaction, and the mineral plant food that is present or supplied. Until we acquire more adequate knowledge of these microorganisms and skill in regulating the carbon/nitrogen relations in our continually cultivated cane soils, we are not in a position to handle nitrogen fertilization in a way that will result in its maximum economic efficiency.



PPmN IN 2 SOILS WITHOUT FILTER CAKE
(AVERAGE OF 4 SERIES)
PPmN
WITH N ADDED
EQUIVALENT TO
600 Lbs. PER ACRE
MANOA SOIL
MAKIKI SOIL
WITH N ADDED
EQUIVALENT TO
300 Lbs. PER ACRE
MANOA SOIL
MAKIKI SOIL
WITH NO N ADDED
MANOA SOIL
MAKIKI SOIL
WEEKS 0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68

Fig. 15



PPm. N in 2 soils, with filter cake, and
fertilized from different sources of nitrogen
(Average of 4 series)
PPm.N
= N from Amm. Nitrate
= N " Amm. Sulfate
= N " Nitrate Soda
On Manoa soil
Added 235 PPm.N
On Makiki soil
Added 192 PPm.N
WEEKS 0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68

Fig. 16

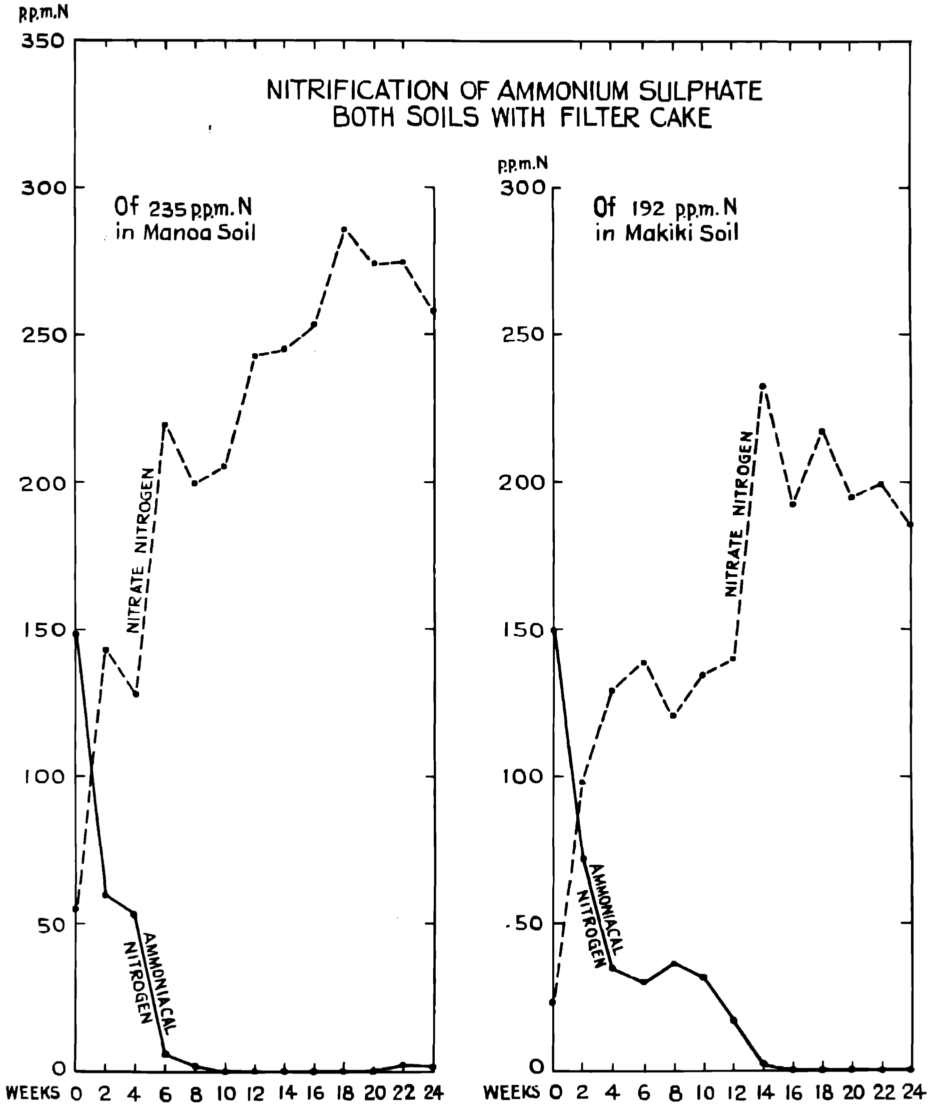

p.p.m.N
350
300
250
200
150
100
50
0
NITRIFICATION OF AMMONIUM SULPHATE
BOTH SOILS WITH FILTER CAKE
Of 235 p.p.m. N
in Manoa Soil
NITRATE NITROGEN
AMMONIACAL NITROGEN
WEEKS 0 2 4 6 8 10 12 14 16 18 20 22 24
p.p.m.N
300
250
200
150
100
50
0
Of 192 p.p.m. N
in Makiki Soil
NITRATE NITROGEN
AMMONIACAL NITROGEN
WEEKS 0 2 4 6 8 10 12 14 16 18 20 22 24

Fig. 17

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD SEPTEMBER 16, 1940, TO DECEMBER 14, 1940

Date	Per pound	Per ton	Remarks
Sept. 16, 1940...	2.67¢	$53.40	Puerto Ricos.
" 24........	2.73	54.60	Philippines.
" 25........	2.75	55.00	Philippines.
Oct. 8........	2.755	55.10	Philippines, 2.76, 2.75.
" 9........	2.78	55.60	Puerto Ricos.
" 14........	2.77	55.40	Philippines.
" 21........	2.80	56.00	Puerto Ricos, Philippines.
" 23........	2.83	56.60	Cubas.
" 24........	2.85	57.00	Philippines.
" 29........	2.87	57.40	Puerto Ricos, Philippines.
Nov. 6........	2.90	58.00	Puerto Ricos, Philippines.
" 13........	2.905	58.10	Philippines, 2.91; Puerto Ricos, 2.90.
" 14........	2.90	58.00	Philippines.
" 22........	2.85	57.00	Cubas.
Dec. 4........	2.865	57.30	Cubas, 2.85; Puerto Ricos, 2.88; Cubas, 2.88.
" 5........	2.87	57.40	Cubas.
" 10........	2.915	58.30	Philippines, 2.90, 2.93.
" 12........	2.95	59.00	Philippines.
" 14........	2.93	58.60	Puerto Ricos.

THE HAWAIIAN PLANTERS' RECORD

Vol. XLV SECOND QUARTER 1941 No. 2

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Some Considerations of the Polarographic Method of Quantitative Analysis:

The polarographic method of chemical analysis differs from spectrographic analyses in that current-voltage relationships of a solution under observation pass through specific orderly and characteristic changes as metallic or organic constituents of the solution progressively deposit out and register their presence or their concentration in the process of dissolution. In spectroscopy a photograph of the spectrum of an incandescent substance is imposed upon a sensitive plate which, with calibrated reference adjuncts, renders it possible to "analyze" the plate and thereby determine the character and relative concentration of chemical elements originally present in the specimen.

These two methods of analysis are complementary because one may supplement the other or, at times, replace the other, depending upon the analyses to be performed.

Spectrographic studies have been described from time to time in this journal. The current discussion features a comprehensive exposition of the theory and practice of polarographic chemical analyses.

Varietal Differences of Sugar Cane in Growth, Yields, and Tolerance to Nutrient Deficiencies:

The varieties H 109, 31–2806, 32–1063 and 32–8560 were grown in a complete nutrient solution and in solutions lacking each of the following elements: nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, and boron. The development of nutrient deficiency symptoms and the detrimental effects on cane growth, cane and sugar yields, and juices of each variety in the various deficiency series are discussed. It is interesting to note that some varieties manifested a much higher degree of tolerance to certain deficiencies than others and that varieties have different nutritional requirements.

Sorption of Potassium and Ammonium by Hawaiian Soils:

Plant nutrients may be leached from soils wherever rain or irrigation water penetrate the soil to depths below the root zone. Where such penetration occurs the ability of the soil to unite with added soluble fertilizer salts is of major importance, for by this means leaching is greatly retarded.

This paper deals with a study of factors influencing the retention of soluble bases by soils. The factor of greatest importance in the retention of potassium appears to be the level of available potassium in the soil. Other factors shown to influence the sorption of potassium and also that of ammonium are the concentrations of these salts in water penetrating the soil, the rate of penetration and the degree of base saturation, or acidity of the soil.

Contributions of the Entomologists to Hawaii's Welfare:

Many insects coming from distant lands will almost always be more destructive in Hawaii than in their places of origin if suitable food plants are present. Our equable climate, small native insect fauna and great isolation peculiarly combine to favor the multiplication of new pests coming in without the natural enemies that check them in their home countries. This precarious state is unavoidable and the Territory will always need the services of trained entomologists. An account is given of some of the insect problems Hawaii has faced and the methods applied in their solution together with recommendations for the future.

Some Observations on the Fluctuations of Moisture Content in the Sugar Cane Plant:

Some evidence is offered that the moisture contents in the growing points, the leaf sheaths and the mature sticks of sugar cane may experience significant variations in moisture content from day to night, although the plant is growing in a soil adequately supplied with water. It is suggested that this effect is caused by a withdrawal of water from the plant, by transpiration, at a rate greater than the rate of supply by the roots.

It is also suggsted, although the proof is inadequate, that such diurnal fluctuations of water content may be of significance in the sugar economy of the plant. More complete studies are necessary to establish this point.

Potash Requirements for Sugar Cane:

An investigation which has had as its objective the determination of the potash requirements for optimum sugar yields as contrasted with the potash uptake by the cane plant tells a story of luxury consumption of potash, but also indicates that most of the potash which is taken up will be returned to the soil providing the cane leaves and trash are left behind in the field at harvest.

Some Considerations of the Polarographic Method of Quantitative Analysis*

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The polarographic method of quantitative analysis is attracting the attention of many analytical chemists and workers in applied fields. This is a relatively new technique applied to substances in solution, and chiefly to solutions containing the heavy metals and certain organic substances. The method is based on preparation and interpretation of current-voltage curves obtained during the electrolysis of dilute solutions containing electro-reducible or electro-oxidizable substances.

This method is especially useful for the rapid analysis of small quantities of solutions containing substances in micro-concentration; for example, one cubic centimeter of a solution containing five parts per million of zinc may be analyzed with comparative ease. Further, when the analysis has been concluded, the solution remains practically unaltered and may be used for other purposes.

This paper presents a general account of the principle, apparatus, and operating technique of the polarographic method as based upon the authors' experiences in the construction and operation of polarographs of several types. Another purpose of the paper is to acquaint readers with the possibilities and limitations of employing this method, with special reference to agricultural analyses.

HISTORICAL REVIEW

The early and fundamental studies of the polarographic method of analysis were carried on by Heyrovský in about 1923. An empirical equation in agreement with the theory of the polarographic method was suggested by Ilkovič (4). MacGillavry and Rideal (10) derived a more refined form of Ilkovič's equation which gave closer agreement between theory and practice. Heyrovský and Shikata (2) invented the polarograph, an instrument which automatically records the current-voltage curves on a moving sheet of photosensitive paper. Maas (8) and Hohn (3) worked out many of the practical applications of the polarographic technique and did much to create interest in this method in Europe. Maassen (9) applied the method to the analysis of steel, and Hamamoto (1) to organic compounds.

Little interest was shown by American scientists in polarography until quite recently. Kolthoff and Lingane (5) have made a comprehensive study of the method and have repeated and checked much of the European work. A discussion of the applications of the polarograph to organic chemistry was presented by Müller (11). Walkley (14) gives a general account of the principles, experimental technique, advantages, and limitations of the method. Stout *et al.* (12, 13) report procedures for determining heavy metals in plant tissue by the same method.

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Operation of a Simple Apparatus

A fundamental apparatus for obtaining current-voltage curves is shown in Fig. 1. In this diagram, *A* is a dropping mercury cathode, *B* is the electrolysis cell containing the liquid to be analyzed; and *C*, a pool of mercury, is the anode or quiet elec-

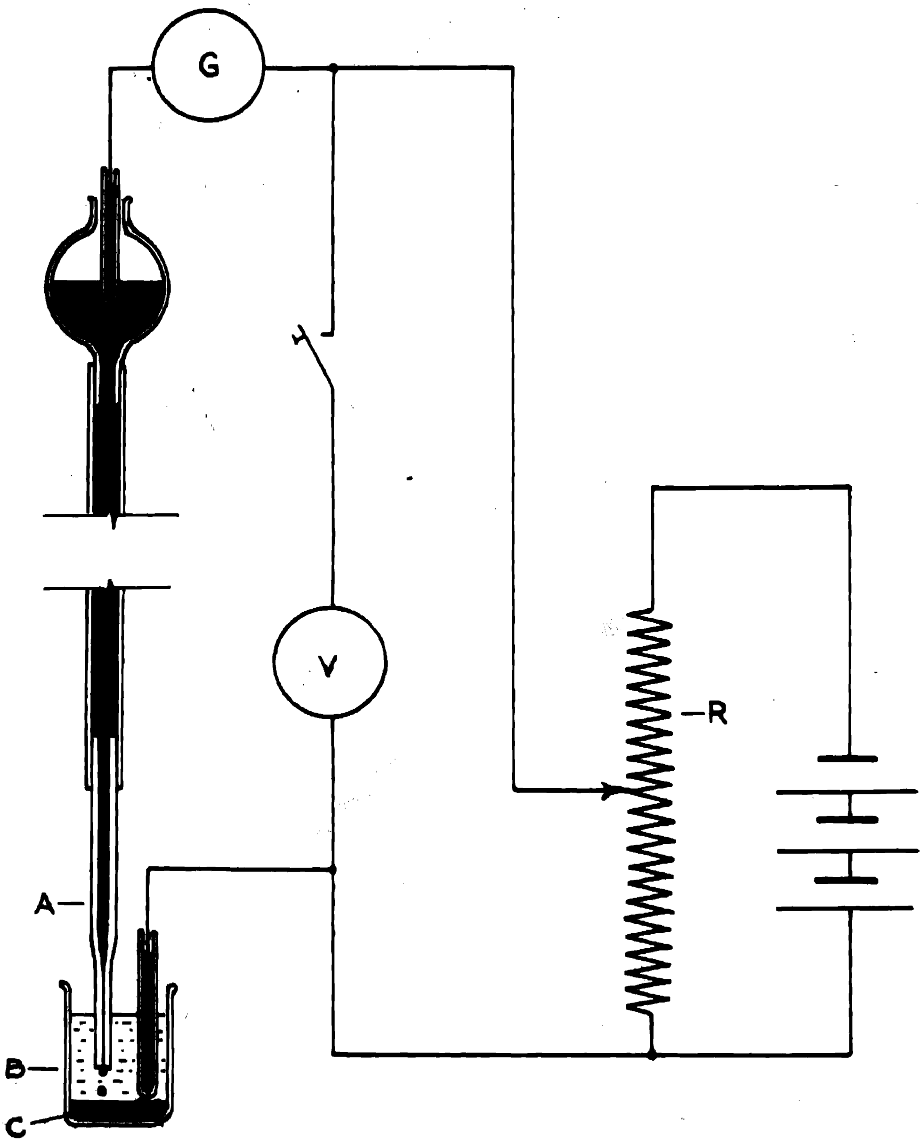

Fig. 1. Simple circuit for obtaining current-voltage curves with a dropping-mercury electrode.

trode. The galvanometer (*G*) which is placed in series with the cell measures the current flowing through it. This current is very small, seldom exceeding 50 microamperes. A potential varying from zero to four volts is applied across the cell by

means of the variable resistances (R), the amount being measured by the voltmeter.

The current-voltage relationship of a solution containing an electro-reducible ion is obtained by electrolyzing the solution in the cell, noting the changes in current as the voltage is increased from zero in successive steps, and graphically presenting these data.

If the dropping mercury electrode is made positive, oxidation takes place at the dropping electrode, and the waves obtained are those of the electro-oxidizable substances.

Fig. 2 shows the current-voltage curve or polarogram obtained when a 0.1 N ammonium acetate solution containing 50 p.p.m. of zinc was electrolyzed. From a study of this polarogram, it may be observed that there is only a slight slope in the portion of the curve AB. The current flow at the voltages corresponding to this

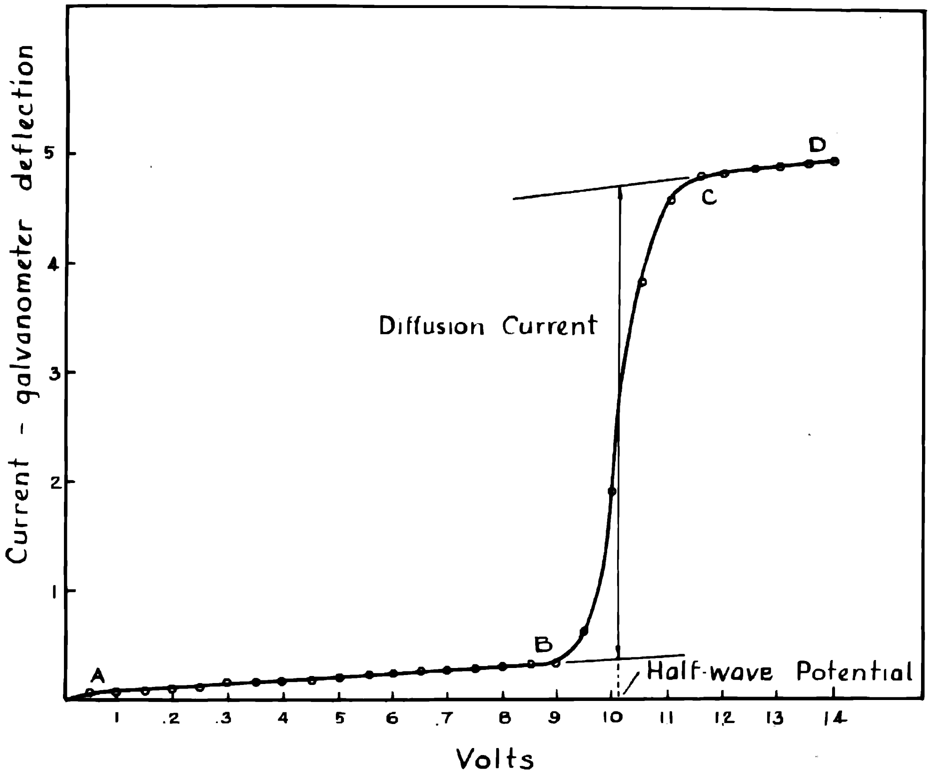

Fig. 2. Current-voltage curve of 0.1 N ammonium-acetate solution, pH 4.6, containing 50 p.p.m. of zinc.

portion of the curve is termed the *residual current*. Its amplitude may be considered as being controlled by the condenser system which embraces the dropping cathode and quiet anode and for that reason is sometimes referred to as the *condenser current*. The potential corresponding to the point B is known as the *decomposition potential* of zinc.

At this potential the zinc ions begin to deposit and amalgamate with the successive hanging mercury drops on the electrode. This causes a lowering of the concentration of zinc ions near the electrode, and a diffusion of zinc ions toward the

dropping electrode begins. As the potential is increased, the rate of deposition increases until a point is reached where the solution immediately surrounding the electrode is maintained almost completely denuded of zinc ions. Thereafter no further increase occurs in the rate of deposition since the rate of diffusion of zinc ions to the electrode under a uniform concentration gradient is the limiting factor. For this reason the current at potentials above the point where the rates of deposition and diffusion of the zinc ions become constant is termed the *limiting current* (C—D, Fig. 2).

The zinc ions are drawn to surfaces of the dropping electrode in two ways: (1) By the diffusion caused by the difference in concentration between the area immediately surrounding the electrode and the body of the solution, and (2) by electrical migration of ions due to the potential difference between the electrodes. In general it can be said that the *limiting current* is composed of two currents—the *diffusion current* and the *migration current.* Since the current through a solution of electrolytes is carried impartially by all ions present, the relative concentrations of these ions will determine to a large extent the amount of current carried by a particular kind of ion. If a large concentration of a salt is present in the solution with a reduction potential greater (more negative) than zinc, then the portion of the current carried by the zinc ions will be negligible. In such instances the *limiting current* has only one important component, the *diffusion current,* and the *limiting current* will be proportional to the concentration of zinc ions in solution. The term, *indifferent salt,* is given to a salt which is placed in the solution to eliminate the factor of the migration current. In the illustration given above (Fig. 2), ammonium acetate was the indifferent salt. Thus quantitative polarographic analysis is dependent upon controlling the conditions of electrolysis so that the limiting current or step height is directly proportional to the concentration of reducible ions in solution.

The voltage corresponding to a point midway on the polarographic wave is called the *half-wave potential.* Every reducible ion has its characteristic half-wave potential. However, this potential may be shifted by changing the pH or the electrolytes present in the solution. In an unknown solution the species of ion causing a particular polarographic wave is not always self-evident. When several electro-reducible ions are present, a current-voltage curve having several waves will be obtained and the position and height of each wave will then correspond to a particular species of ion. The simultaneous determination of several ions is possible if the half-wave potentials of the ions differ from one another by at least 0.2 volt. Otherwise an overlapping of the waves will occur making the wave-height determinations difficult and often impossible. Fig. 3 shows the polarogram of lead, copper, bismuth, and cadmium in a 5 per cent solution of sodium potassium tartrate. In this instance the waves are sufficiently separated to determine simultaneously and quantitatively the concentrations of the four significant ions present. Unfortunately ideal polarograms such as the one illustrated are almost never encountered in any practical application of the polarographic method.

Technical Details of Capillaries and Electrolysis Vessels

Much of the successful operation of the polarographic method is dependent upon the dropping mercury electrode. The drop time of the mercury will vary with the

solution and also with the applied potential; however, with a properly functioning electrode, the weight of the drops of mercury falling per minute will remain con-

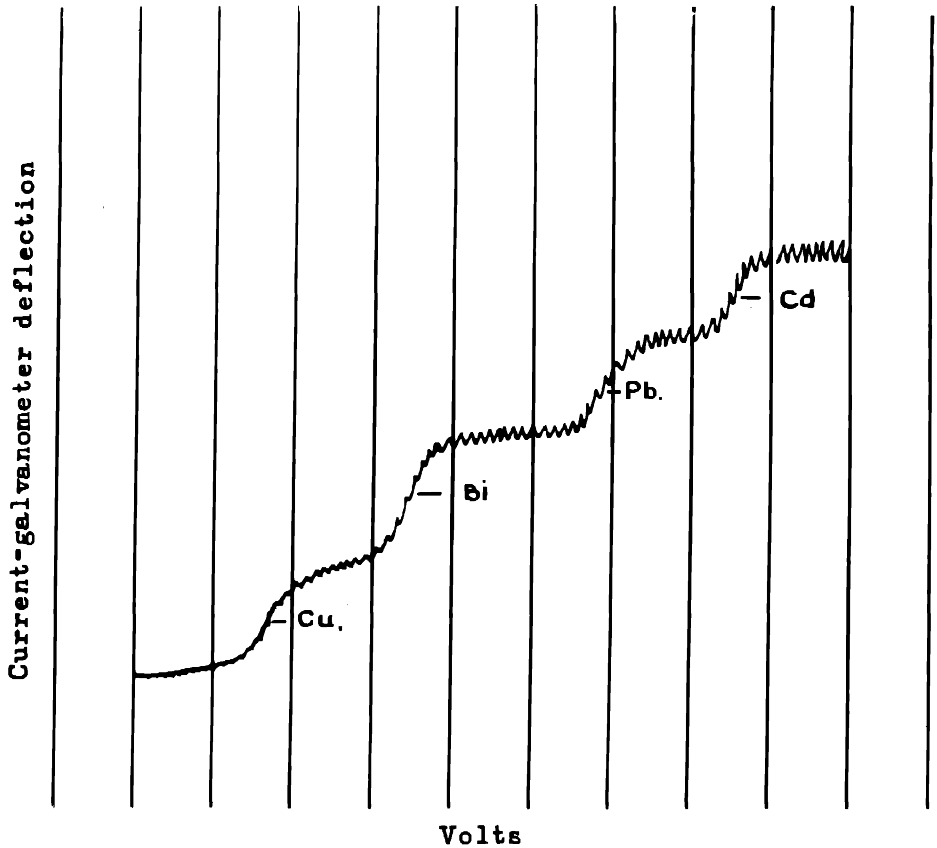

Fig. 3. Polarogram of a 5 per cent solution of potassium-sodium tartrate containing copper, bismuth, lead, and cadmium.

stant. In order for this to be true, several precautions must be taken: (1) The capillary must be dry; (2) the mercury must be pure; and (3) the capillary must be kept as free from vibrations as possible.

Experience has shown that a capillary with a drop time of from 4 to 6 seconds under a pressure of 60 centimeters of mercury is satisfactory. If the drop time is too fast, a linear relationship is not realized between the diffusion current and the concentration of the solution; if it is too slow the oscillations of the galvanometer become so large that accurate measurement of the diffusion current is difficult.

A satisfactory capillary may be made from thoroughly cleaned and dried pyrex capillary tubing having an outside diameter of 8 millimeters and a bore of 1 millimeter. The capillary is thickened in a flame to reduce the bore and then drawn out until the outside diameter is approximately 2 to 3 millimeters. Capillaries fabricated in this manner have sufficient rigidity to withstand hard usage. After the drawn capillary has been broken in the center, the drop rate may be tested by connecting the capillary to a mercury reservoir with 50 cm. of clean dry surgical rubber

tubing and placing the tip in a solution of indifferent electrolyte (0.1 N ammonium acetate or potassium chloride under a pressure of 60 cm. of mercury). If the drop time is more than 6 seconds per drop the rate can be increased by breaking off short lengths of the tip. The drop rate of the same electrode in distilled water is considerably slower than in a dilute solution of an electrolyte.

Once a satisfactory electrode has been prepared, precautions should be taken to preserve it. The diffusion current obtained by using one capillary cannot be compared with that obtained by using another, unless certain constants of both are known. Consequently it is more convenient always to use one carefully standardized capillary. Because rubber tubing connecting the capillary with the mercury reservoir necessitates frequent cleaning of the mercury and the capillary, a more desirable permanent electrode may be secured by sealing the capillary to an all-glass arrangement similar to that described by Kolthoff and Lingane (5).

When the capillary is not in use the mercury reservoir should be lowered until no drops appear, and the tip of the capillary should be immersed in either pure mercury or pure distilled water. When lowering the reservoir the tip of the capillary should remain free from a solution of electrolyte because of the danger of contamination by sucking back.

Many different types of electrolysis vessels or cells have been suggested for use in the polarographic method. The type of cell employed depends upon the amount of solution available and upon the character of the solution. If the solution need not be oxygen-free, a beaker with a pool of mercury in the bottom is satisfactory. However, dissolved oxygen interferes with many of the analyses for which the polarograph is commonly used, and in such cases the oxygen is usually removed from the solutions by bubbling hydrogen or nitrogen gas through them. Depending upon the volume of solution used, from 5 to 30 minutes are required to remove the oxygen completely. A small volume of solution will, therefore, speed up operations. Kolthoff and Laitinen (6) demonstrated that sodium sulfite would remove dissolved oxygen successfully from a potassium chloride solution.

THE POLAROGRAPH

The steps previously described for obtaining polarographic current-voltage curves are slow and tedious. For this reason Heyrovský and Shikata (2) invented the polarograph, which automatically records the current-voltage curves on photographic paper. Various models of polarographs may be purchased on the market or may be constructed at small cost by laboratory staffs with shop facilities. A diagram and a photograph of the systematic arrangement of parts of the polarograph constructed in this laboratory are given in Figs. 4 and 5. The 6-inch transite drum (D), which is wound with twenty turns of No. 18 Nichrome wire, comprises the slide wire of a rotary potentiometer. This drum is rotated at a speed of about 45 seconds per revolution by an electric motor connected through a system of reduction gears. The potential, usually 2 volts, applied across the wire is controlled by the rheostat (R) and measured by the voltmeter which remains connected in the circuit. The sliding contact (F), which is connected to the anode of the electrolysis cell, impresses an increasing E.M.F. on the cell as the drum is rotated. The contact is attached to a half-nut arrangement that moves along the drum on a screw, geared

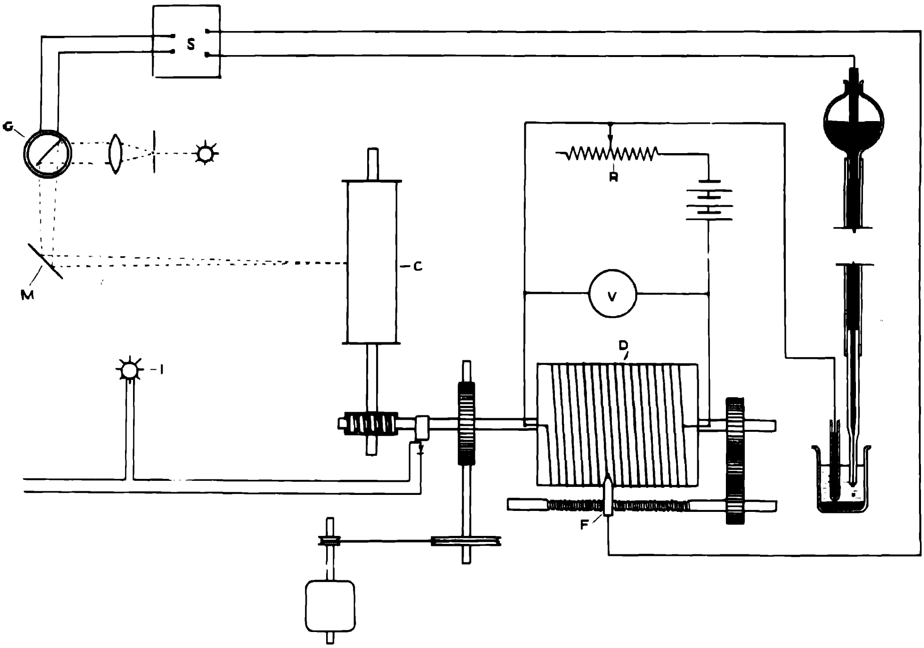

Fig. 4. Systematic diagram of the polarograph constructed in this laboratory.

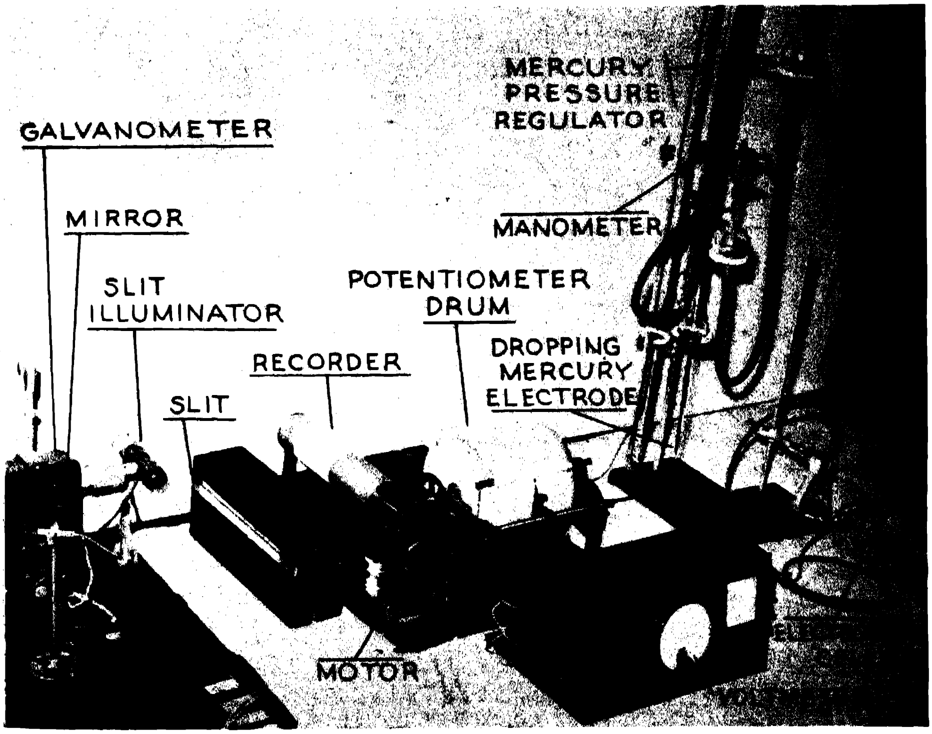

Fig. 5. Photograph of polarograph now in use.

to the main shaft. In this way continuous contact is maintained as the drum is rotated.

The recording cylinder (C), on which photographic paper is wrapped, is geared to the potentiometer drum in such a way that they rotate together, one revolution of the drum corresponding to a movement of one centimeter of the photographic paper. The recording cylinder is housed in a light-proof box with a narrow slit extending parallel to the axis of the cylinder. The light from the galvanometer lamp is focused on the recording cylinder. The adjusting mirror (M) adjusts the light beam without disturbing the galvanometer (G). The slit illuminator (I), connected to a switch operated by a cam on the shaft of the potentiometer drum, causes a light to flash on the slit once each revolution of the drum. Thus thin lines are automatically printed on the paper, marking off equal increments of applied voltage. For example, if 2 volts are applied across the slide wire then each turn of the drum will give an increase of one-tenth volt and the recording paper will be lined in one-tenth volt increments. The Ayrton type of shunt (S), connected in parallel with the galvanometer, governs the fraction of the total current that passes through it, thus controlling the amount of deflection.

The polarograph has several advantages over manual measurement. The actual time involved in getting a polarogram is much less. Several curves can be recorded on the same paper. The record is continuous rather than a series of points so that discontinuities or irregularities are recorded that might be overlooked in the manual method. The records are permanent and can easily be filed away for future reference.

However, a polarograph is not essential to polarographic research and analyses. Much of the theoretical work, in which very sensitive current- and voltage-measuring instruments are required, may be obtained more easily by the manual method.

Analytical Application of the Polarographic Method

The polarographic method for quantitative analysis is of importance chiefly because small quantities of very dilute solutions can be handled. Solutions with concentrations from 10^{-3} to 10^{-5} molar are most conveniently adaptable. However, the method has not as yet been perfected for routine examination of unknown mixtures of substances; consequently it cannot replace the spectrograph. Our experience has shown that at least a year's experience is required for an operator to become proficient in the use of the polarographic method.

Operation of the instrument itself is not difficult, for the procedure is actually simple and rapid. However, care and experience are required in devising methods for preparing satisfactory solutions of the substances to be analyzed. One of the common difficulties encountered is the presence of a large concentration of ions which have a decomposition potential lower (less negative) than that of the ions to be determined. For example, determining the amount of lead in a zinc compound is quite simple, the decomposition potential for lead being about —0.5 volt and for zinc about —1.0 volt. However, it would be impossible to determine the amount of zinc in a lead compound without first removing most of the lead by a standard chemical separation. The compensation method, which reduces the diffusion current of an interfering ion, has been suggested by Lingane and Kerlinger (7) and

by others. This compensation is accomplished by sending a current, from an outside source, equal in magnitude to the interfering diffusion current, through the galvanometer in the opposite direction.

Another difficulty commonly encountered is the presence of ions with a decomposition potential close to that of the ions to be determined. In such a case, an overlapping of waves occurs which must be resolved before measurements can be obtained. Many ingenious devices have been suggested for separating overlapping waves. For example, Stout *et al.* (12) have shown that the waves for nickel and zinc can be successfully separated by adding potassium thiocyanate.

In general it may be said that for any type of substance which is to be determined by polarography, it is necessary first to perfect a method of preparing a suitable solution of the substance; usually by trial and error.

The practical application of the polarographic method is well demonstrated by determinations made in this laboratory of the amounts of zinc in various samples of perchloric acids, prior to employing perchloric acid to wet-ash samples of plant material for zinc determinations. Five cc. aliquots of the perchloric acids were evaporated to dryness in 30 cc. pyrex beakers and the residue treated with 2 N hydrochloric acid and evaporated to dryness twice. Each residue was then dissolved in 2 cc. of a solution, adjusted to pH 4.6, which was 0.1 N in respect to ammonium acetate and 0.025 N in respect to potassium thiocyanate. The current-voltage curves or polarograms for the solutions prepared as above are given in Fig. 6. An evaluation of the heights of the polarographic waves for zinc showed the perchloric acid samples 1–5 to contain 0.19, 0.22, 0.19, 0.21, and 3.0 p.p.m. of zinc respectively. The perchloric acid in sample 5 was a technical grade, and a higher shunt ratio was used in obtaining the polarogram.

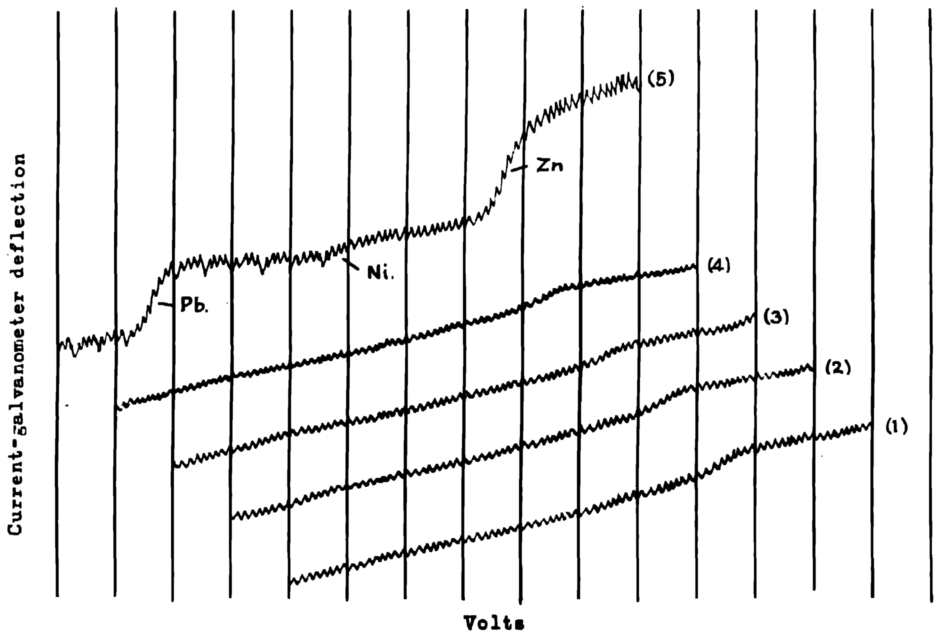

Fig. 6. Polarograms of zinc determination in samples of perchloric acids.

There are numerous acceptable procedures for establishing the relationship between the measured step height or diffusion current and the concentration of the solution electrolyzed. When a large number of determinations are being made a

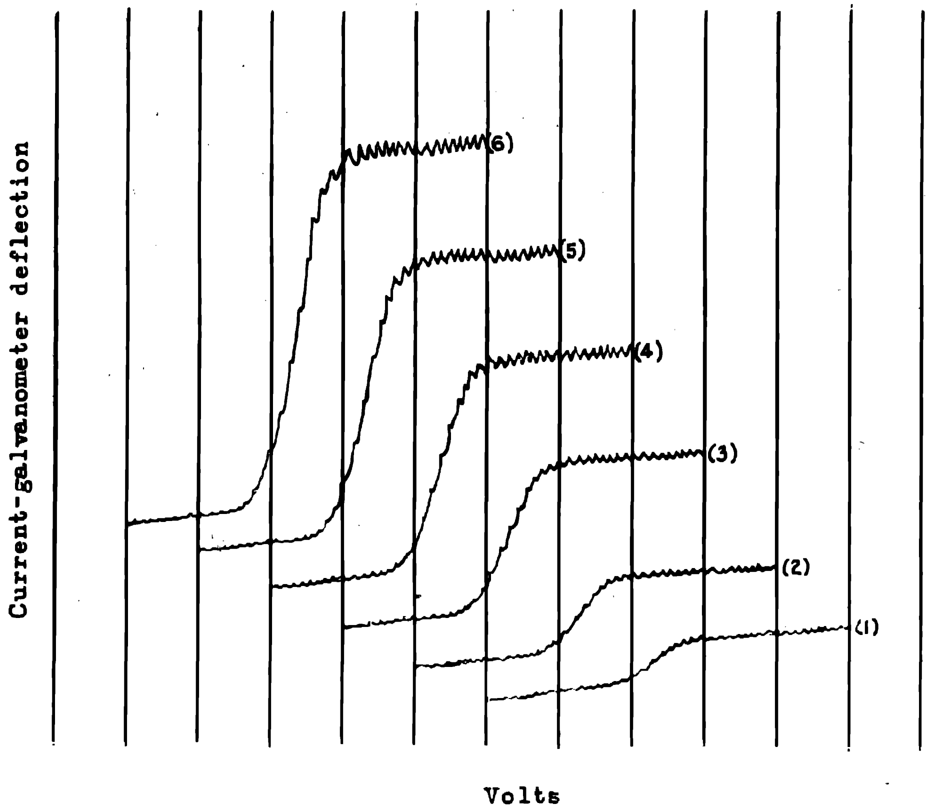

Fig. 7. Polarographic waves measured for a zinc standardization curve.

standardization curve is convenient. The measured heights of the polarographic waves shown in Fig. 7 were plotted to obtain such a curve for zinc. The solutions were prepared by evaporating suitable aliquots of a standard zinc chloride solution to dryness and dissolving the residue in 5.00 cc. of a 0.1 N ammonium acetate solution which was 0.025 N in respect to potassium thiocyanate and adjusted to pH 4.6. When the step heights were plotted against the concentrations of the solution the standardization curve (Fig. 8) was obtained. The tangent of this line was calculated by the method of least squares and found to be 0.255. This tangent value was used for calculating the concentrations of unknown solution in preference to obtaining the value from a direct reading on the standardization curve. This method is only applicable when the drop time and the temperature are rigidly controlled. It is also possible to use an addition method, that is, after a polarogram of an unknown solution has been prepared a known amount of the ion to be determined is added to the unknown solution and another polarogram prepared. From the increase in height resulting from the known addition the original concentration of the unknown may be calculated.

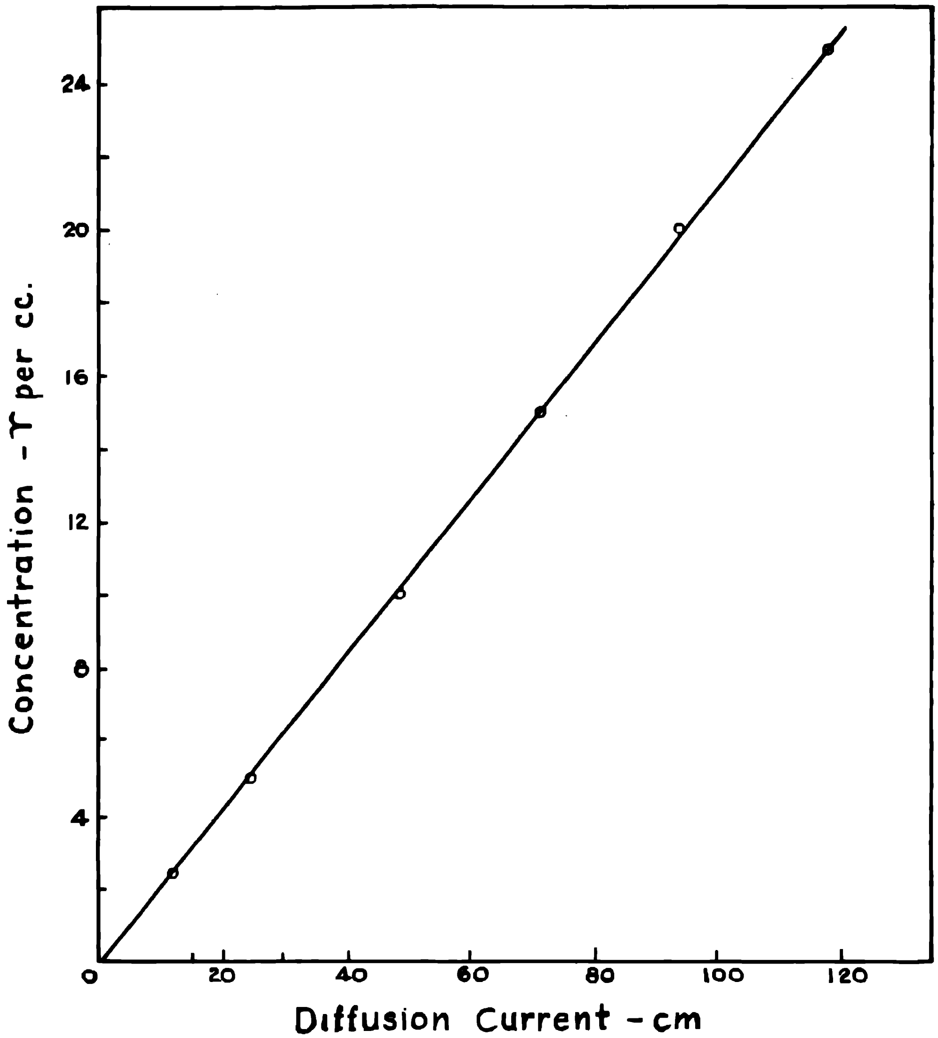

Fig. 8. Standardization curve for zinc in a 0.1 N ammonium-acetate and 0.025 N potassium-thiocyanate solution, adjusted to pH 4.6.

Summary

1. A brief account of the history, principles, and operation of the polarographic method of analysis has been presented.

2. A description of the construction and operation of a polarograph is given.

3. Possible analytical applications and limitations of the polarographic method are illustrated and discussed.

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Varietal Differences of Sugar Cane in Growth, Yields, and Tolerance to Nutrient Deficiencies

By J. P. MARTIN

It has been known for many years that the ten elements, carbon (C), oxygen (O), hydrogen (H), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), and iron (Fe) are indispensable for normal plant growth, and more recently manganese (Mn), zinc (Zn), boron (B), copper (Cu), silicon (Si), and a few other elements have been added to this list. Inasmuch as many compounds of these elements occur in the soil, it is extremely difficult to determine the soil's exact chemical composition. Nutritive substances applied to the soil as fertilizers contribute toward increased crop yields; the optimum amounts of these materials to be applied are often determined by chemical analyses of the soil and by pot and field experiments.

The chemical composition of plants varies greatly, depending largely on environmental conditions under which they are grown and their age; differences, of a smaller magnitude, occur within varieties of a given species. The rate of absorption of the mineral elements by plants changes with their different stages of growth.

The nutritional requirements of plants are frequently studied in water or sand cultures. The preparation of the solutions with distilled water and chemically pure salts makes it possible to study the behavior of the plants under controlled conditions. For the past ten years considerable research work has been conducted at this Station on the nutrition of the sugar cane plant in water and sand cultures. Most of these studies have had to do with inducing and studying deficiency symptoms of specific elements on a number of the commercial cane varieties; to a much lesser degree the effects of excesses of certain elements have been investigated. To date it has been definitely shown that the following elements are essential for satisfactory cane growth in culture solutions: N, P, K, Ca, Mg, S, Fe, Mn, and B. Insufficient work has been carried out with copper, zinc, and silicon to comment on their indispensability to the growth of sugar cane. Under field conditions we have observed deficiency symptoms of the following elements only: N, P, K, Mg, Fe, and Mn.

A knowledge of the nutrient requirements of a cane variety is of the greatest importance in securing a maximum growth in terms of productiveness. It has often been demonstrated that varieties respond differently to differential fertilization and this is also true for a single variety.

The primary purpose of this paper is to record growth and yield differences of H 109, 31–2806, 32–1063, and 32–8560 when grown in a complete nutrient solution and in solutions lacking nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, and boron respectively. In order that all varieties within a deficiency series would receive the same treatment, one plant of each variety was grown in the same container for each series. Marked growth differences soon be-

came apparent in the varieties and it was evident that some varieties were much more tolerant than others to the various nutrient deficiencies.

Experimental Procedure

During May 1940 an equal number of cuttings of H 109, 31–2806, 32–1063, and 32–8560 were planted in black sand and irrigated with tap water; eight weeks later shoots of uniform size of each variety were removed from the original cuttings and placed in a complete, aerated, nutrient solution. The plants were grown for a period of six weeks in this solution during which time all plants made what appeared to be a normal growth. On August 12, 1940, plants of uniform size, health and vigor of each variety were again selected and one plant of each of the four varieties was placed in each of ten 4-gallon earthenware containers with glazed inner surfaces. In one series the plants received the standard nutrient solution while in the other nine series the plants were grown in nutrient solutions lacking each of the following elements: nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese and boron. With this arrangement each plant of each variety received the same treatment in the various series.

The culture solutions used throughout the experiment for the control and deficiency series were prepared with distilled water and chemically pure salts, thus making it possible to study the reaction of the plants in media of a known chemical composition. The pH value of all series was adjusted to 5.2 at the time the solutions were prepared; however, the pH values of the solutions changed somewhat by the time the solutions were renewed which was every 7 to 10 days. All solutions were aerated continuously. The complete and the deficient nutrient solutions were prepared the same as those used in 1933 and 1934 by Martin (1, 2), wherein nutritional deficiency symptoms of H 109, POJ 2878, Badila, Yellow Caledonia and POJ 36 were recorded.

The arrangement of the four varieties in each container was identical; for example, as shown in Fig. 2, the variety H 109 was placed in front and left, 31–2806 in front and right, while 32–1063 was placed in back and left, and 32–8560 in back and right. The reader is asked to bear this arrangement of the plants in mind when referring to Figs. 1, 3, and 4 since the individual plants therein are not labelled.

Inasmuch as the test was designed to study the leaf and stalk development of the varieties in relation to the deficiency of each of the nine elements, no attempt was made to study root development. A study of the latter would involve growing each variety in individual containers. Since the deficiency symptoms of the elements under study in this experiment have been previously described in detail (1, 2) they will not be so treated in this article.

All series were photographed on December 10, 1940, and it will be noted in Figs. 1, 3, and 4 that the plants in the control series appear with each group of the deficiency series; with this grouping it is easier to compare the plants in each deficiency series with those in the control series. The variety 31–2806 in each series, after being photographed with the other varieties, was given to Dr. H. Clements of the University of Hawaii for chemical analyses, the results of which will be made available by him at a later date; hence no data on 31–2806 appear in Tables I or II.

Discussion of Results

On February 14, 1941, or 6 months after the plants were placed in the deficiency series, Brix readings were recorded from the upper, middle, and lower portion of each stalk of H 109, 32–1063 and 32–8560 in each series. These data presented in Table I were obtained with the hand punch and hand refractometer. It will be noted that the average Brix of the upper, middle, and lower portion of each stalk (Table I) is in most instances somewhat higher than the Brix for the same variety and treatment in Table II.

The experiment was harvested February 18, 1941, with the assistance of L. R. Smith of the Agricultural department, and the results are given in Table II. Each stalk was weighed and the juice of the entire stalk of each variety was expressed in the small "Cuba A Mill" and the yield figures in the table are based on the expressed juice. The Brix readings were determined by means of the polariscope. Three stalks of cane per foot of line or 30,000 stalks per acre were used as the basis for estimating the tons cane per acre (TCPA), tons sugar per acre (TSPA) and the tons sugar per acre per month (TSAM) as given in Table II.

The two graphs in Fig. 5 show the cane and sugar yields at harvest from H 109, 32–1063 and 32–8560 (age nine months) in the control and deficiency series. It will be noted that a close correlation occurs between the cane and sugar yields for each variety and that the effects of the deficiencies were more marked on the sugar than on the cane yields.

TABLE I

BRIX READINGS OF H 109, 32–1063, AND 32–8560 IN THE CONTROL AND DEFICIENCY SERIES AS DETERMINED BY THE HAND REFRACTOMETER

		Com.	—N	—P	—K	—Ca	—Mg	—S	—Fe	—Mn	—B
H 109	U*	19.4	13.2	11.8	7.4		7.6	17.0	14.2	17.6	11.6
	M*	22.2	16.4	20.8	13.6	16.0	5.6	19.5	15.0	21.8	21.2
	L*	18.8	17.5	20.4	13.0		6.6	18.4	15.0	18.4	17.2
Average		20.1	15.7	17.7	11.3		6.6	18.3	14.7	19.3	16.7
32–1063	U	21.5	19.4	18.2	8.0		11.4	20.8	23.0	22.2	22.0
	M	23.6	21.6	22.8	11.4	17.0	12.2	21.6	24.8	23.2	22.2
	L	23.4	22.2	23.0	13.2		13.6	20.4	23.4	23.0	21.4
Average		22.8	21.1	21.3	10.9		12.4	20.9	23.7	22.8	21.9
32–8560	U	22.6	19.3	18.8	20.8		15.4	22.4	21.4	22.4	23.0
	M	24.6	22.7	22.0	23.0	22.0	17.6	22.6	22.8	23.2	22.4
	L	22.8	22.8	22.0	21.4		13.4	22.8	23.2	22.0	21.4
Average		23.3	21.6	20.9	21.7		15.5	22.6	22.5	22.5	22.3

* U, M, L, = upper, middle, and lower portion of stalk.

TABLE II

COMPARATIVE YIELDS OF H 109, 32–1063, AND 32–8560 WHEN GROWN IN A COMPLETE NUTRIENT SOLUTION AND IN SOLUTIONS LACKING EACH OF THE FOLLOWING ELEMENTS: N, P, K, Ca, Mg, S, Fe, Mn, and B

		Harvesting results of deficiency series					Yields per acre*		
Deficiency series	Variety	Wt. per stalk lbs.	Brix	Purity	Q. R.	Sugar per stalk lbs.	TCPA (9 mos.)	TSPA (9 mos.)	TSAM
Control (Complete Nut. Soln.)	H 109	3.20	19.0	89.5	7.7	.42	48	6.2	.69
	32–1063	3.75	21.6	86.6	7.2	.52	56.25	7.8	.87
	32–8560	4.50	21.8	89.0	6.8	.66	67.5	9.9	1.10
Nitrogen	H 109	0.30	17.4	86.2	9.0	.03	4.5	.5	.06
	32–1063	1.75	19.2	89.1	7.7	.23	26.25	3.4	.38
	32–8560	1.30	20.1	90.0	7.2	.18	19.5	2.7	.30
Phosphorus	H 109	2.00	17.5	84.6	9.2	.22	30.0	3.3	.37
	32–1063	2.25	19.2	84.4	8.4	.27	33.75	4.0	.44
	32–8560	3.00	19.5	85.1	8.2	.37	45.00	5.5	.61
Potassium	H 109	1.10	12.8	75.0	15.6	.07	16.5	1.1	.12
	32–1063	2.10	12.2	68.9	19.2	.11	31.5	1.6	.18
	32–8560	3.20	19.7	87.8	7.7	.42	48.0	6.2	.69
Calcium	H 109, 32–1063, 32–8560	The growing point of each plant was dead at harvest.							
Magnesium	H 109	0.60	7.5	57.3	46.8	.01	9.0	.2	.02
	32–1063	1.90	11.8	79.7	15.1	.13	28.5	1.9	.21
	32–8560	1.90	15.8	81.0	11.0	.17	28.5	2.6	.29
Sulphur	H 109	1.40	16.5	86.1	9.5	.15	21.0	2.2	.24
	32–1063	2.00	19.4	83.0	8.6	.23	30.0	3.5	.39
	32–8560	2.50	20.9	86.1	7.5	.33	37.5	5.0	.56
Iron	H 109	1.20	14.6	77.4	12.9	.09	18.0	1.4	.16
	32–1063	1.40	22.4	84.4	7.2	.19	21.0	2.9	.32
	32–8560	2.00	21.6	88.0	7.0	.29	30.0	4.3	.48
Manganese	H 109	2.25	18.5	90.3	7.8	.29	33.75	4.3	.48
	32–1063	3.75	20.4	87.3	7.5	.50	56.25	7.5	.83
	32–8560	3.40	20.6	88.8	7.2	.47	51.00	7.1	.79
Boron	H 109	4.00	17.9	89.3	8.2	.49	60.00	7.3	.81
	32–1063	2.30	19.8	87.9	7.7	.30	34.50	4.5	.50
	32–8560	2.20	21.7	87.6	7.0	.31	33.00	4.7	.52

* Based on 3 stalks per foot of line or 30,000 stalks per acre.

Control Series: The control plants which received the complete nutrient solution throughout the experiment made a uniform rate of growth at all times. The color of the leaves was normal, and the stalk diameters and lengths (best shown in Fig. 2, pot No. P 10) compared favorably with those of field cane. The growth of the four varieties in this series may be compared with that of the same varieties in the nine deficiency series in Figs. 1, 2, 3, and 4. The varieties 32–1063 and 32–8560 produced the best growth, the millable cane of each stalk at harvest being slightly over six feet in length. The growth of H 109 and 31–2806 was approximately equal, but was less for each variety than that of 32–1063 or 32–8560; this is again

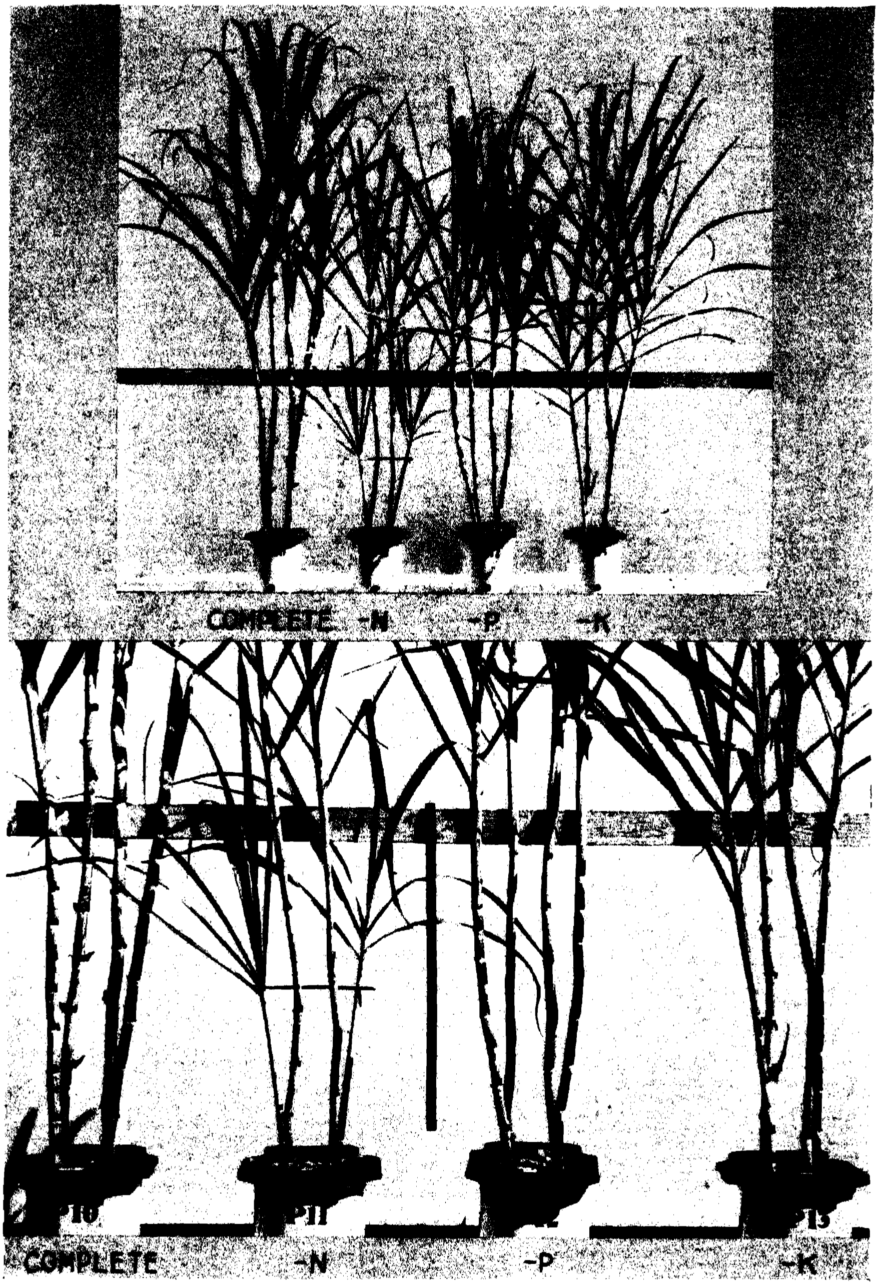

Fig. 1. The upper photograph shows the growth of H 109, 31–2806, 32–1063 and 32–8560 in the complete, minus-nitrogen, minus-phosphorus, and minus-potassium series; the lower photograph shows, in greater detail, stalk differences of each variety in the four series.

shown by the weight of each stalk in Table II—H 109 weighed 3.2 pounds, 32–1063 weighed 3.75 pounds while 32–8560 weighed 4.5 pounds. When expressed in yields per acre all varieties showed an excellent performance—the tons of sugar per acre per month for H 109, 32–1063, and 32–8560 being .69, .87 and 1.10 respectively.

At the age of 9 months the three varieties were found to have excellent juice qualities (Table II). It is of interest to note in Table I that the middle portion of each stalk had the highest Brix and this was the case in several of the other series. It is of further interest to note the high sucrose content of the control plants especially since they were grown in water cultures and since nitrogen was supplied in the culture solution at the rate of 126 parts per million (378 pounds per acre) every 7 to 10 days. At no time was water or nitrogen a limiting growth factor. From the standpoint of yields 32–8560 was without question much superior to 32–1063 or H 109; the variety 32–1063 proved to be second best.

Minus-nitrogen Series: The first symptoms of nitrogen deficiency appeared eight days after nitrogen had been omitted from the solution and thereafter the leaf and stalk symptoms became more acute. The growth of each variety was greatly retarded, as shown in Figs. 1 and 2, pot No. 11; however, it was extremely interesting to observe the superior growth of 32–1063 and 32–8560 to that of H 109 and 31–2806. These differences are best shown in Fig. 2 wherein the label of each variety points to the division between the green- and dry-leaf portion of the stalk.

The weight per stalk of each variety was far less than in the control series and marked differences resulted among the varieties within the series; the weight expressed in pounds per stalk being .30 for H 109, 1.75 for 32–1063 and 1.30 for 32–8560 (Table II). Of the three varieties 32–8560 had the best juice, followed by 32–1063 and H 109.

The very low yields in this series can be directly attributed to the lack of nitrogen. Two hypotheses are suggested to explain the superior growth of 32–1063 and 32–8560 to that of H 109 and 31–2806: (1) 32–1063 and 32–8560 each absorbed more nitrogen than either H 109 or 31-2806 while they were growing in the complete nutrient solution, or (2) 32–1063 and 32–8560 are more efficient in their utilization of nitrogen than H 109 and 31–2806.

Minus-phosphorus Series: The growth (in terms of length) of all varieties in this series was approximately the same (Fig. 1, pot No. P 12), but stalk lengths and stalk diameters were considerably less than in the control series. The leaves were not as dark a green and were somewhat narrower than those on the control plants. The older leaves manifested a premature yellowing, drying and dying at the tips. At no time in our nutritional studies have phosphorus deficiency symptoms been as definite as the deficiency symptoms of the other elements which have been studied.

As shown in Table II the variety 32–8560 had the greatest weight per stalk, the best juice and the greatest yields per acre, while the variety 32–1063 was second in these respects. It is shown in this experiment that a deficiency of phosphorus reduced the juice quality and cane yields of each variety.

Minus-potassium Series: One month after the element potassium was omitted from the solution definite leaf deficiency symptoms were observed. Later a retardation of growth, a yellowing and spotting of the older leaves, a premature drying and dying from the tips of the older leaves, and a reddish discoloration of the upper surfaces of the midribs were present. Of the four varieties, H 109 manifested the most acute symptoms, with 31–2806 next. The growth of 32–8560 was much superior to that of 32–1063 and the leaf symptoms of potassium deficiency were less

severe; the growth of these two varieties was much superior to that of H 109 and 31–2806 (Fig. 1, pot No. P 13).

The variety 32–8560 proved to be outstanding in this series, it having the best juice and producing by far the greatest cane and sugar yields (Table II). The

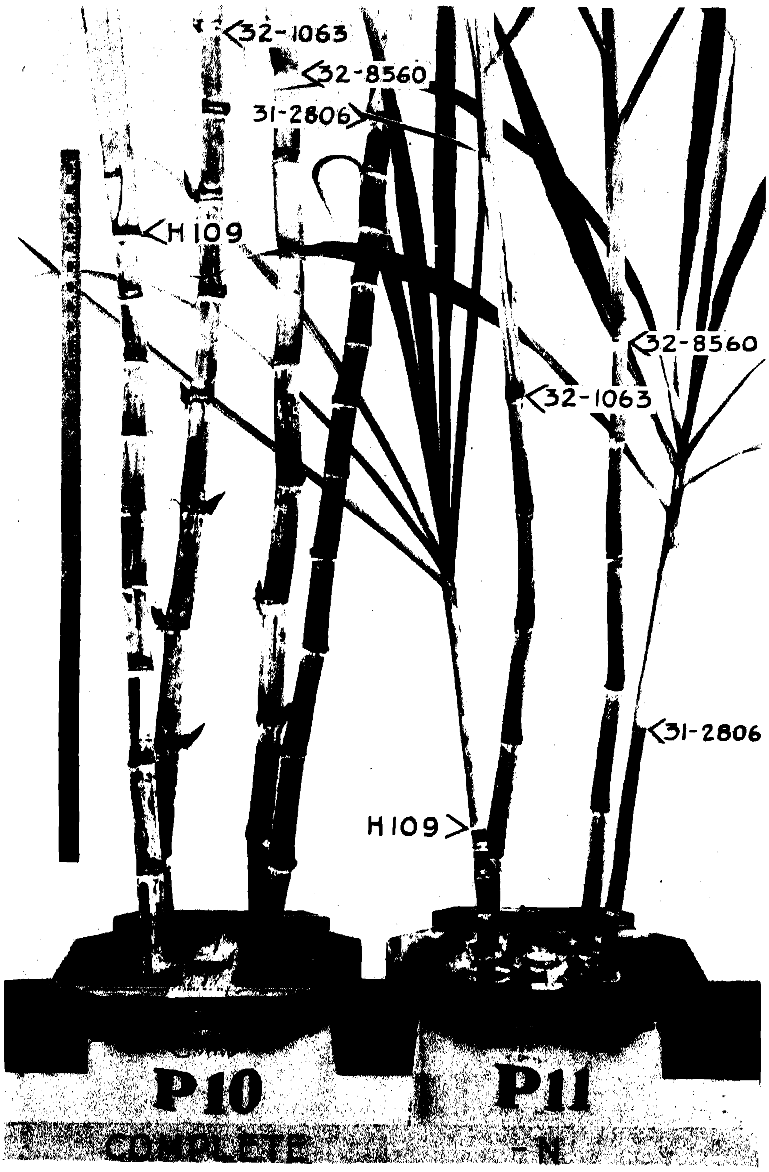

Fig. 2. Note the marked differences in growth and stalk diameter of the plants in the minus-nitrogen series (right) from those of the plants in the complete nutrient solution (left). The label of each variety indicates the division of the green- and dry-leaf portion of the stalk. The arrangement of the varieties in Figs. 1, 3, and 4 is identical to that in this figure: H 109 front and left, 31–2806 front and right, 32–1063 rear and left, and 32–8560 rear and right.

variety 32–1063 produced more cane than H 109 but had poorer juices, although the sugar yields of 32–1063 were slightly higher than H 109.

The results from this deficiency series indicate that the variety 32–8560 would be a much superior cane to grow in soils deficient in potash than either 32–1063 or

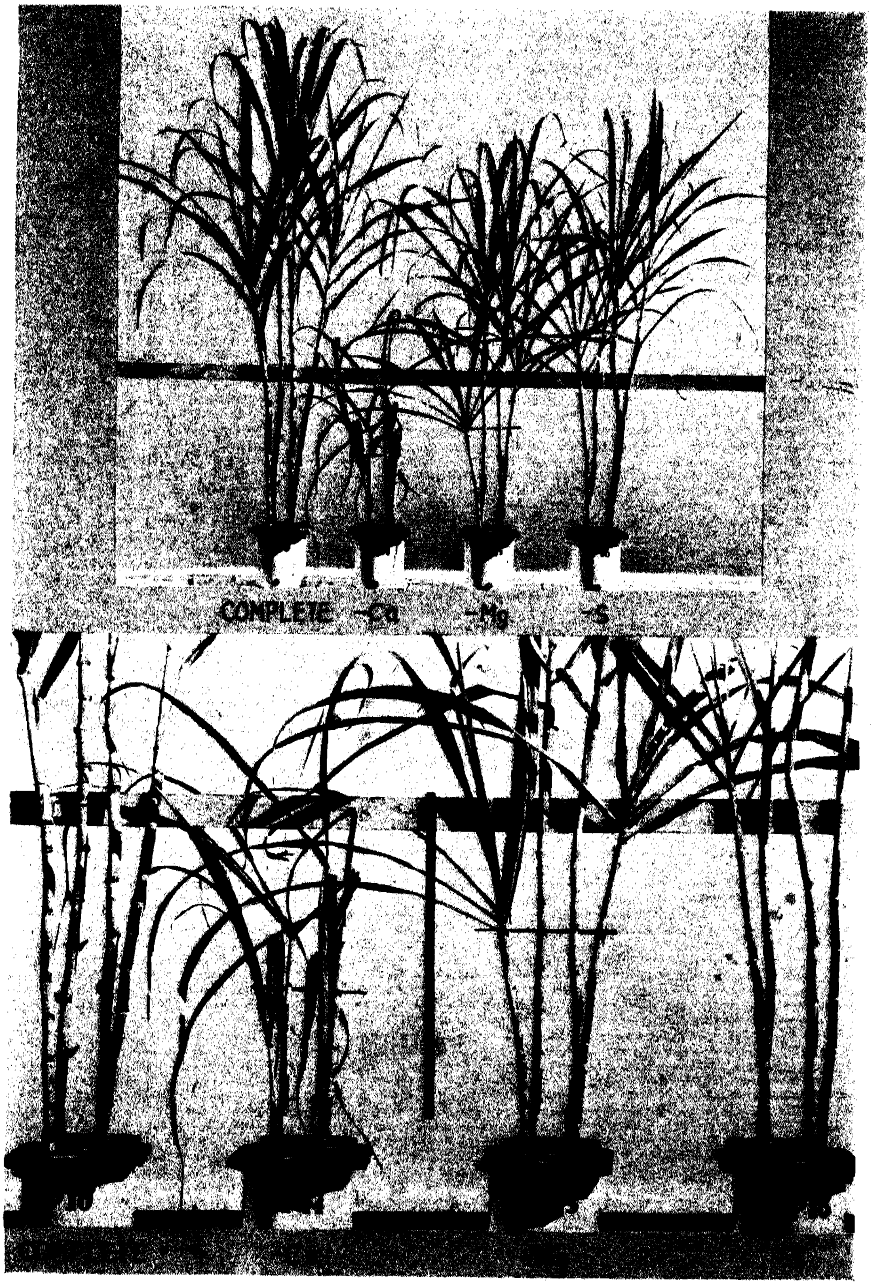

Fig. 3. Showing total growth and stalk differences of each of the four varieties in the minus-calcium, minus-magnesium, and minus-sulphur series. The growth of the control plants is shown on the left.

H 109. It is apparent that 32–8560 is much more tolerant to potash deficiency than 32–1063 or H 109.

Minus-calcium Series: At the end of four weeks clear-cut calcium deficiency symptoms, as characterized by a chlorotic condition of the leaves, a spotting on the older leaves and a retardation of growth, were apparent. These symptoms soon became more acute, the youngest leaves were extremely weak and made no further growth, and the spindle of each plant died. The growth of the plants four months after they were deprived of calcium is shown in Fig. 3, pot No. P 14 together with the growth of the control plants (pot No. P 10).

Inasmuch as the growing point of each variety had died and the plants had made little or no growth, no attempt was made to harvest the plants in this series.

Minus-magnesium Series: It will be noted in Fig. 3, pot No. 15 that the growth of all plants was greatly depressed in the absence of magnesium and that the stalk size was less than that of the control plants. The first leaf symptoms of magnesium deficiency were observed 22 days after this element was omitted from the solution. The variety H 109 produced the least amount of growth and manifested the most acute leaf symptoms, while 31–2806 was slightly less affected in these respects. The growth of 32–1063 and 32–8560 was about equal, and was much superior to that of H 109 and 31–2806. The deficiency symptoms on 32–1063 and 32–8560 were less pronounced than on the other two varieties.

A deficiency of magnesium had a very detrimental effect on the juices and cane and sugar yields of all varieties, as noted in Table II; the variety H 109 was most affected, with 32–1063 next while 32–8560 was least affected. Similar results have been observed in other experiments.

An application of magnesium to the soil, in the form of magnesium sulphate, might improve the juice quality of a variety where poor juices are experienced in soils which are deficient in magnesium.

Minus-sulphur Series: The effects on the plants subsequent to the removal of sulphur from the solution were quite similar to those when nitrogen is omitted. A paling of the young leaves was noted at the end of three weeks and as the experiment continued all leaves developed a light lemon-yellow color (quite similar to nitrogen deficiency) and growth was retarded (Fig. 3, pot No. P 16). Of the four varieties in this series the variety H 109 made the least amount of growth, while the growth of the other three varieties was quite uniform. The growth of all varieties was considerably less than in the control series. As shown in Table II a deficiency of sulphur resulted in poorer juices and lower cane and sugar yields.

Sulphur plays a very important part in the plant's metabolism, especially in the formation of proteins which in turn enter into the making of protoplasm; thus a retardation of growth results with a sulphur deficiency. To date sulphur deficiency symptoms have not been recorded on field cane.

Minus-iron Series: Twelve days after this series had been underway iron deficiency symptoms, recognized by a pale striping on the young leaves, appeared on 32–1063 and 32–8560. At the end of 6 to 8 weeks the leaf symptoms on all plants were very conspicuous, the younger leaves were entirely white and the plants were greatly depressed in growth (Fig. 4, pot No. P 17). The varieties 32–1063 and 32–8560 made the best growth, with H 109 next best, while 31–2806 produced the

smallest amount of growth. There was a sharp contrast between the iron-deficient plants and those in the control series both in color and growth.

An absence of iron had little effect on the juice quality of 32–1063 or 32–8560 but it was responsible for poor juices in H 109 (Table II). The cane weight of

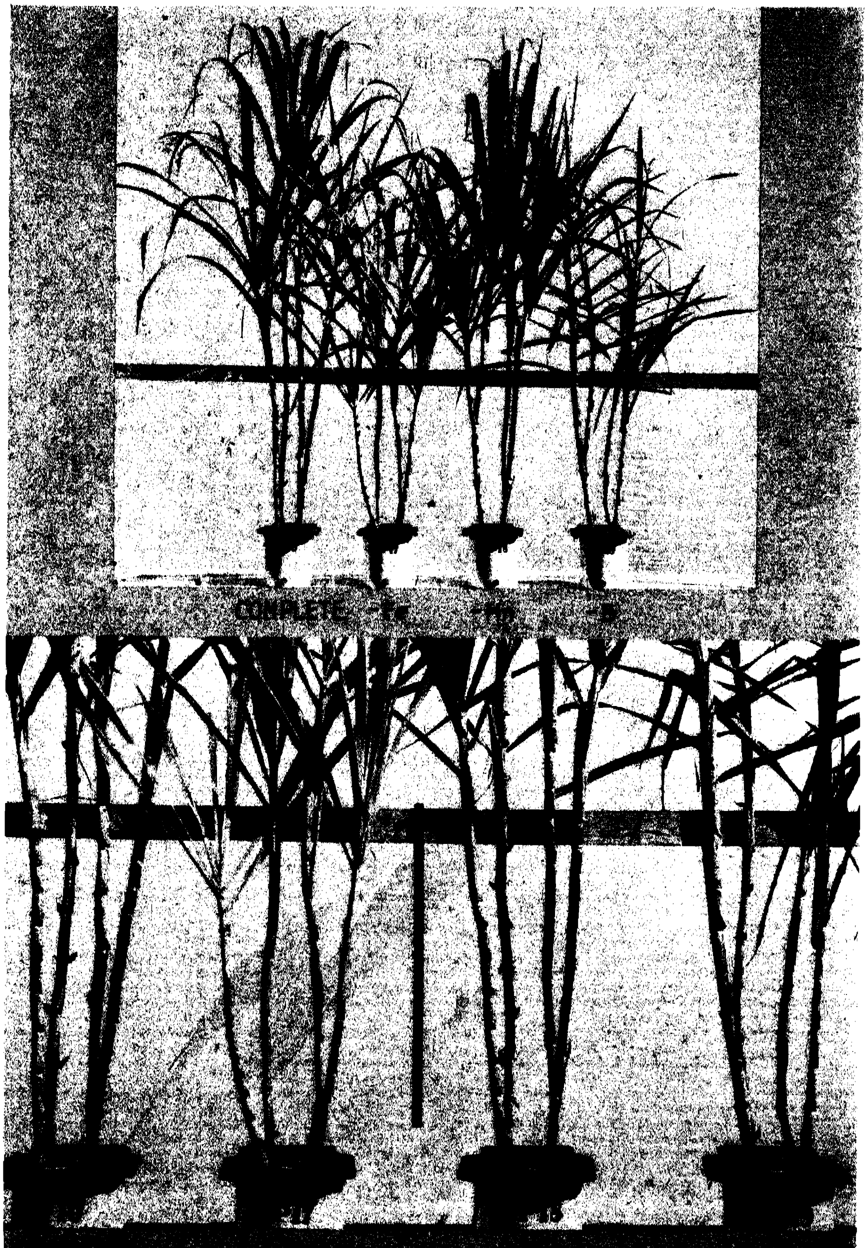

Fig. 4. Showing the effects of iron, manganese, and boron deficiencies on the growth of H 109, 31–2806, 32–1063, and 32–8560. The control plants are on the left.

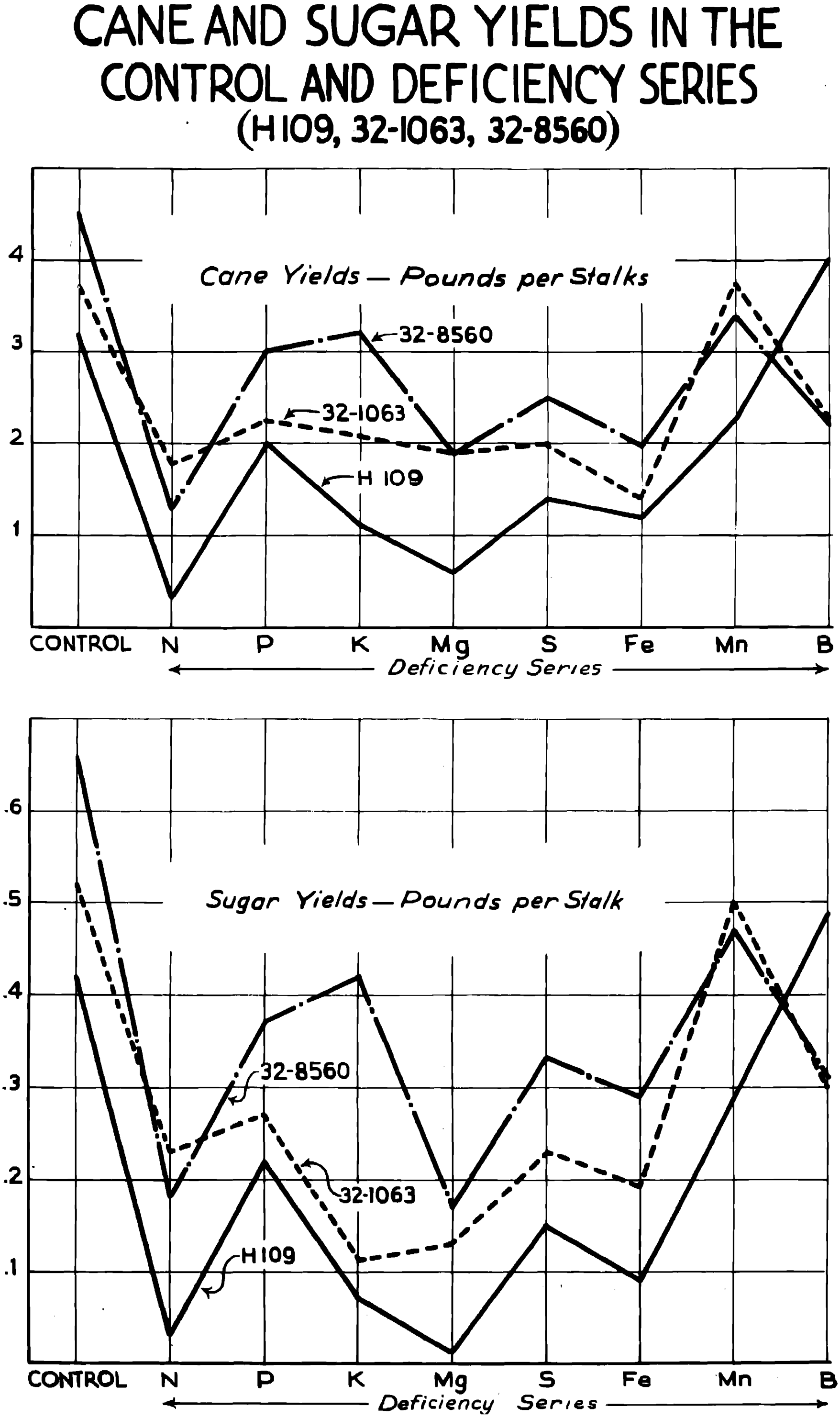

Fig. 5. Comparative cane and sugar yields of H 109, 32–1063, and 32–8560 in the complete and deficiency series.

each of the three varieties was markedly reduced thus accounting for the low sugar yields when compared with those of the control plants.

With a reduction of chlorophyll the process of photosynthesis—a putting together of raw materials by light energy to form carbohydrates—is greatly retarded. It has been shown that iron does not enter into the composition of chlorophyll but that it is necessary for the normal growth of all plants. The immobility of iron within plants has been demonstrated a number of times; for example: when new cane leaves develop on plants in nutrient solutions lacking iron they soon become chlorotic if iron is not returned to the solutions.

Minus-manganese Series: Very few leaf symptoms of manganese deficiency developed on any of the plants and, as shown in Fig. 4, pot No. P 18, the growth of the plants was almost equal to that of the control plants. Toward the end of the experiment the alternating dark green and light green leaf stripes typical of manganese deficiency had developed.

In previous studies symptoms of manganese deficiency were not detected until after 2 months or more. Only extremely small quantities of manganese (.25 of a part per million which is equivalent to approximately .75 of a pound per acre) are essential for normal cane growth in nutrient solutions. The slightest trace of this element from any source would prevent the development of the symptoms.

Even though small differences were noted in total length of growth, a noticeable reduction in cane weight for each variety was apparent and the juice quality was lower, both of which accounted for the lower cane and sugar yields than in the control series (Table II). Of the three varieties in this series 32–1063 was the most tolerant to manganese deficiency.

Minus-boron Series: A conspicuous reduction in growth of each variety and definite leaf symptoms of boron deficiency were noted. It was very interesting to observe the superior growth of H 109 to that of 31–2806, 32–1063 and 32–8560 (Fig. 4, pot No. P 19); it is possible that H 109 either took up more boron while in the complete nutrient solution or that it has a much higher tolerance to a lack of boron than the other three varieties.

The first leaf symptoms appeared 12 days after boron was omitted from the solution and their development thereafter was identical to those described in 1934 on H 109, POJ 36, POJ 2878, Yellow Caledonia and Badila by Martin (2).

The abnormal growth of all varieties was characterized by depressed growth, especially in the growing-point region, and the development of distorted leaves with definite chlorotic leaf markings. At the end of 4 months the young leaves of 31–2806, 32–1063 and 32–8560 were badly distorted and exhibited symptoms similar to those of pokkah boeng disease which is caused by the fungus *Gibberella Fujikuroi* (Saw.) Wr. (*Fusarium moniliforme* Sheldon).

The harvest data, Table II, show that H 109 produced more cane and sugar but had a slightly lower juice quality than the other two varieties and also lower than it had in the control series. Both 32–1063 and 32–8560 produced considerably less cane and sugar than in the control series. The variety H 109 was much more tolerant to boron deficiency than 32–1063 or 32–8560. This is the only series wherein H 109 was superior in cane and sugar yields to the other two varieties.

Summary

From the foregoing results we may conclude that:

1. Normal growth, and cane and sugar yields of each variety were depressed when any one of the nine elements was omitted from the solution.

2. Typical deficiency symptoms of each element developed on all varieties, but it was clearly demonstrated that some varieties manifested a much higher degree of tolerance to certain deficiencies than others.

3. The juice quality of all varieties was definitely affected when certain elements were omitted from the nutrient solution, and the effect on some varieties was more marked than on others.

4. Varieties have different nutritional requirements.

5. The juice quality of a variety under field conditions may be improved in specific areas by applying certain elements to the soil.

Literature Cited

(1) Martin, J. P., 1934. Symptoms of malnutrition manifested by the sugar cane plant when grown in culture solutions from which certain essential elements are omitted. The Hawaiian Planters' Record, 38: 3–31.

(2) ———, 1934. Boron deficiency symptoms in sugar cane. The Hawaiian Planters' Record, 38: 95–107.

Sorption* of Potassium and Ammonium by Hawaiian Soils

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Wherever rainfall or irrigation water penetrates the soil to depths below the root zone, there is a possibility of loss of plant nutrients by leaching. In the absence of a fluctuating water table, the leached nutrients are not recoverable by the crop.

The ability of soils to prevent loss by leaching varies extremely. It is common knowledge that when soluble phosphates are applied to Hawaiian soils, the phosphate constituent of the fertilizer unites with the soil to such a degree that losses of this nutrient by leaching are wholly negligible. Furthermore, much of the phosphate thus fixed is so insoluble that it is not readily available to plants. At the other extreme are the nitrates. The soil does not possess the ability to unite with nitrogen in this form, and hence nitrates are very susceptible to leaching.

Under some conditions soils are known to combine with certain of the bases‡ commonly introduced as fertilizers. Under other circumstances they apparently do not. Hance and coworkers (6) studied the effect of high-potassium irrigation water (25 p.p.m. K_2O) on the amount of potassium in certain soils of the Hawaiian Commercial and Sugar Co., Ltd. Although several hundred pounds of potassium per acre had been applied annually over a period of years, the soil retained none of it. Enormous amounts of sodium chloride had been similarly applied to this area, yet examination of the soil profile to a depth of 5 feet failed to reveal amounts of this salt which were greater than those in adjacent virgin areas, which had never received irrigation water. Further evidence that under some circumstances the soil does not react with and hold sodium is to be found in a consideration of the quantities of this base which are present in rain water. Collins and Williams (3) found that the average amount of chlorine in 8 samples of Maui rain water was 11 p.p.m., while Farden (4) showed that rain water at the chemical laboratory of the Pineapple Producers' Cooperative Association in Honolulu contained 23 p.p.m. of chlorine. If these results are averaged and expressed in terms of sodium chloride, on the arbitrarily chosen basis of 60 inches of rainfall, soil in a

* "Sorption" is replacing the older term "fixation" in referring to the process whereby soluble bases are taken up by soil and retained in a form available to plants. The term "fixation," insofar as it applies to potassium, is now usually employed with reference to a process whereby the nutrient is fixed in the soil in a form which is unavailable to plants.

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‡ The bases commonly involved in base-exchange reactions of the soil are sodium, potassium, ammonium, calcium, and magnesium. Doubtless other bases such as manganese (Mn^{++}) may take part in the process to some extent. Acid or dissociable hydrogen, although not a base, is frequently referred to as such, since in base-exchange reactions it behaves similarly. A better term for the positively charged ions which take part in base-exchange reactions is "cations."

region of this rainfall might be expected to receive 400 pounds of sodium chloride per acre per year from the atmosphere. Studies of Magistad, Horner, and Dean (9) showed that the average amount of exchangeable sodium in ten pineapple soils obtained from six islands, when expressed as sodium chloride, amounts to little more than 1,000 pounds in the surface foot of soil. If these figures approximate the true situation, then the addition of 400 pounds of sodium chloride per acre per year for untold years has not resulted in the accumulation of large quantities of the salt. It is apparent, therefore, that the soil does not always combine with this base. The following table, taken from a report on a lysimeter study by Magistad (10) indicates leaching losses from two Oahu soils which had never received fertilizer. It will be noted that losses of sodium are much greater than corresponding losses of other bases, particularly potassium. This appears to indicate also that soils receive sodium chloride from the atmosphere and do not retain it.

TABLE I

MINERALS LOST FROM UNFERTILIZED AND UNCROPPED SOILS BY LEACHING DURING A PERIOD OF 1 YEAR

Constituent	Lysimeter No. 1 Wahiawa (Lbs. per acre)	Lysimeter No. 2 Hawaiian Pineapple Co., Field 4415 (Lbs. per acre)
Silica (SiO_2)	19.497	10.804
Alumina (Al_2O_3)	0.908	4.742
Calcium (CaO)	62.582	68.597
Soda (Na_2O)	122.619	147.372
Potash (K_2O)	15.076	28.074
Phosphoric Acid (P_2O_5)	0.459	0.401
Nitrate Nitrogen (N)	54.781	101.881
Ammonia Nitrogen (N)	1.474	0.936
Rainfall (inches)	58.450	91.630

Adapted from a report of Dr. O. C. Magistad (10).

MECHANISM OF BASE EXCHANGE

Many chemical reactions proceed to completion and are practically irreversible. Thus when an excess of sulfuric acid is added to a solution of barium chloride, the barium is transformed almost completely to insoluble barium sulfate and the resulting concentration of barium chloride is practically zero. This reaction is not reversible except in very slight degree.

$$BaCl_2 + H_2SO_4 \rightleftharpoons BaSO_4 + 2HCl$$

Fixation of phosphates by the soil may be compared to a complete reaction of this type. Thus, Ayres (1) found that soils were able to reduce the concentration of phosphate solutions with which they were in contact from 100 p.p.m. P_2O_5 to <0.1 p.p.m. P_2O_5.

Other chemical reactions may not continue to completion but reach an equilibrium, with appreciable quantities of all of the reacting substances present. Such is

the situation when magnesium nitrate and ammonium hydroxide react to form ammonium nitrate and a precipitate of magnesium hydroxide. This reaction is readily reversible.

$$Mg(NO_3)_2 + 2NH_4OH \rightleftarrows Mg(OH)_2 + 2NH_4NO_3$$

If either magnesium nitrate or ammonium hydroxide is withdrawn in part from the solution, the reaction will be readily shifted to the left and part of the precipitated magnesium hydroxide will dissolve. The addition of ammonium nitrate to the solution would similarly shift the reaction to the left and cause some of the precipitated magnesium hydroxide to reenter the solution. If, on the other hand, more magnesium nitrate were added to the original solution, still more magnesium hydroxide would be precipitated. It is to this type of reaction that the sorption of bases by soils more nearly compares.*

The materials responsible for base-exchange reactions in soils are of two totally different types. One of these consists of various clay minerals which have resulted from the weathering of lavas, or of volcanic cinders. The other is the product of the decomposition of plant materials. In either case the constituents responsible for base exchange may be regarded as extremely weak, insoluble acids or as salts of these acids. In highly leached soils from which the bases have been largely lost, the characteristic acidity of these materials appears, and the soil is consequently acid. In neutral soils these insoluble acids are present for the most part in neutralized forms, or as salts, and the bases with which they are in combination are referred to as exchangeable bases.

If the letter X is used to represent the negative radical of the exchange material of the soil, then HX will represent the acid, or hydrogen form, just as the symbol HCl represents hydrochloric acid. Correspondingly, KX, NH_4X and NaX will represent potassium, ammonium, and sodium in combination with the base-exchange material. The hydrogen, potassium, ammonium, and sodium thus indicated become the exchangeable bases, or exchangeable cations, of the soil. A chemical equation may then be written for the reaction between any soluble base and the insoluble acid or salt, as the case may be, comprising the base-exchange material of the soil. Thus the reaction between potassium chloride and a single-base soil, for example a sodium-soil, would be as follows:

$$NaX + KCl \rightleftarrows KX + NaCl$$

The corresponding reaction for a completely leached soil in which only the acid form of the exchange material is present would be:

$$HX + KCl \rightleftarrows KX + HCl$$

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* The more general treatment based upon the law of mass action is as follows: Consider the equation $a + b \rightleftarrows g + h$, in which a reacts with b to form g and h. If one mol of a and one mol of b are involved in the reaction the rate of the forward reaction is $k_1C_a \times C_b$ and that of the reverse reaction is $k_2C_g \times C_h$ where C represents the concentration of the reacting substance and k_1 and k_2 are specific rate constants. At equilibrium the rates of the forward and reverse reactions are the same and hence $k_1C_a \times C_b = k_2C_g \times C_h$ or $\frac{C_g \times C_h}{C_a \times C_b} = \frac{k_1}{k_2} = K$, where K is the equilibrium constant for the entire reaction. At equilibrium the addition of more of a or b, or the removal in part of g or h, will shift the reaction to the right. Conversely, the addition of g or h, or the removal in part of a or b, will result in forcing the reaction to the left.

Ordinarily many bases are combined with the soil exchange material. Under such circumstances the following reaction would approximate the situation qualitatively when a solution of potassium chloride is applied to the soil. In the first instance a soil containing no exchangeable potassium will be considered.

$$\left.\begin{matrix} Ca \\ Mg \\ Na \\ H \\ NH_4 \end{matrix}\right\} X + KCl \rightleftarrows KX + \left\{\begin{matrix} CaCl_2 \\ MgCl_2 \\ NaCl \\ HCl \\ NH_4Cl \end{matrix}\right.$$

If a solution of potassium chloride is shaken with such a soil, potassium will replace some of the cations held by the exchange material and will itself be rendered insoluble thereby, or sorbed. The replaced cations, calcium, sodium, and so forth, will no longer be retained by the exchange material but will be free to move about in the solution. Some of them may again combine with the soil exchange material by displacing still other cations. Now, if the concentration of potassium chloride is increased, the reaction will be forced to the right, more potassium will be sorbed and, correspondingly, more of the other bases will be released. If, on the other hand, some of the potassium chloride could be withdrawn from the solution, the reaction would move to the left, and part of the sorbed potassium would reenter the solution, its place in the exchange material being taken by other cations. Some of the sorbed potassium could also be set free by adding to the solution one or more of the bases which had been displaced by potassium.

Suppose now, that a solution of potassium chloride is shaken with soil which already contains exchangeable potassium, e.g., a normal field soil. Whether or not potassium will enter the exchange material of the soil, to add to the supply already present, will depend upon the concentration of potassium in the solution. If the concentration of potassium in the solution is *greater* than that necessary to establish the level already present in the soil, sorption of potassium will occur. Sorption will continue until the soil and solution are at equilibrium at some new higher level of exchangeable potassium. If a potassium solution *equal* in concentration to that necessary to establish the level of potassium already present, is added to a soil, no net change will result either in exchangeable potassium or in the concentration of the solution. If, however, a solution containing a *lower* concentration of potassium than the equilibrium concentration is added to the soil, the soil will be depleted of exchangeable potassium and the solution will be correspondingly enriched. This process will continue until soil and solution are again at equilibrium with respect to potassium at a new, lower level of exchangeable potassium.*

Let us consider in terms of the mechanism of base exchange, the results which Hance and coworkers (6) obtained in their study of soils in relation to irrigation water at Hawaiian Commercial and Sugar Co., Ltd. It will be recalled that irrigation water containing 25 p.p.m. K_2O did not add to the exchangeable potassium in

* When a solution of a potassium salt percolates through a soil, as it may following the application of a potassium fertilizer in the field, a true equilibrium is not attained so long as the movement of water continues, since the replaced bases are subject to continual removal. However, if the solution percolates slowly, a condition approaching equilibrium results, and the concentration of potassium in the solution will determine whether potassium will be sorbed or given up by the soil.

these soils, in spite of the fact that many hundreds of pounds of K_2O were applied in this manner in the course of each crop. This being the case, and since no evidence was obtained that the irrigation water had depleted the soil of potassium, it must be concluded that this concentration of potassium (25 p.p.m. K_2O) corresponds roughly to the equilibrium concentration between these soils and water of that particular composition.* Similarly, since the level of exchangeable sodium apparently was not altered by the enormous quantities of sodium chloride applied to these soils annually, it must be likewise concluded that approximate equilibrium between soil and solution obtained in the case of this base also. The failure of sodium chloride derived from the atmosphere to accumulate in Hawaiian soils is doubtless also the result of concentrations of the salt which are not above the equilibrium concentration.

Sorption of Potassium and Ammonium

Effect of Concentration and Level of Exchangeable Potassium and Ammonium in the Soil:

If the foregoing interpretation of the mechanism of base exchange is correct, it should be subject to demonstration under the conditions of control possible in the laboratory. In order to test this, substantial quantities of six soils were obtained. Large glass percolation cylinders, 3 inches in diameter, were packed with the air-dried soils to a depth of one foot. Solutions of potassium chloride were then allowed to percolate slowly through the soils. Solutions of three concentrations were employed in this work, namely, 5, 25, and 210 p.p.m. K_2O. One or more of these solutions was percolated through each soil, in increments corresponding to 5 acre-inches. Upon emergence from the soils the solutions were analyzed for potassium. The results of this experiment, together with data pertaining to the soils studied, are shown in Table II.

Referring to the table it will be seen that when potassium chloride solutions containing 210 p.p.m. K_2O, 5 acre-inches of which corresponds to an application of approximately 250 pounds of K_2O per acre were allowed to percolate through the Manoa substation and University farm soils, the resulting sorption of potassium was of a very high order. Thus the concentrations of the percolating solutions were reduced by these soils from 210 p.p.m. K_2O to around 10 to 15 and 5 p.p.m., respectively. On the basis of the earlier discussion of base exchange this concentration (210 p.p.m. K_2O) is far in excess of that necessary to cause the sorption of potassium by these two soils. In fact it is apparent from the concentrations of the leachates that potassium would be sorbed from any concentration above 13 p.p.m. by the Manoa soil and from any above 5.6 by the University soil. When a solution containing 25 p.p.m. K_2O was percolated through a Kona soil the concentration of potassium in the percolating solution was reduced to a little less than 7 p.p.m., and when percolated through the University soil it was reduced to less than 2 p.p.m. A concentration of 25 p.p.m. K_2O is likewise seen to be very much in excess of that

* The work of Fraps and Fudge (5) and of Kelly, Brown, and Liebig, Jr. (7) suggests that the presence of considerable concentrations of sodium, calcium, and magnesium, in irrigation water, may have an appreciable repressing effect upon the sorption of fertilizer salts applied to the soil through this medium. Similarly studies of McGeorge (11) have shown that sorption of a fertilizer base by soil may be depressed by the simultaneous application of another base.

TABLE II

EFFECT OF THE AMOUNT OF EXCHANGEABLE POTASSIUM IN THE SOIL UPON THE SORPTION OF POTASSIUM FROM POTASSIUM CHLORIDE. THE EXTENT OF SORPTION IS INDICATED BY THE DIFFERENCE BETWEEN INITIAL CONCENTRATIONS OF POTASSIUM AND CONCENTRATIONS OF POTASSIUM IN THE CORRESPONDING LEACHATES

Soil	Field pH	Exchangeable potassium per 100 gms. of soil	Exchange capacity per 100 gms. of soil	Potassium saturation	Concentration of K_2O in leachate. Initial concentration 5 p.p.m.				Concentration of K_2O in leachate. Initial concentration 25 p.p.m.			Concentration of K_2O in leachate. Initial concentration 210 p.p.m.*		
		M.E.	M.E.	Per cent	Acre-inches of leachate				Acre-inches of leachate			Acre-inches of leachate		
					1st 5	2nd 5	3rd 5	4th 5	1st 5	2nd 5	3rd 5	1st 5	2nd 5	3rd 5
					p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Kona	5.7	0.40	51	0.78					6.7	6.5				
Manoa (H.S.P.A. substation)	5.0	0.48	32	1.50								10	13	
University Farm (Manoa)	6.5	0.68	42	1.62					2.9	1.6	1.2	5.6	3.3	
Ewa	6.7	1.02	14	7.3					74	15	12			
Kailua (H.A.E.S. substation)	6.2	2.16	26	8.3	22	25	21		62	30	26	116	62	66
Aiea	5.7	1.69	15	11.3	132	60	36	43	178	45	31	182	85	

* 5 acre-inches of this solution are approximately the equivalent of 250 pounds of K_2O per acre.
1 M.E. of potassium/100 gms. of soil equals about 1,180 pounds of K_2O per acre-foot, or approximately 360 pounds of R.C.M. K_2O per acre-foot.

required to bring about sorption of potassium by these soils. Soils such as these would probably be able to obtain much potassium from irrigation waters rich in potassium.

When potassium-chloride solutions were percolated through the Aiea and Kailua soils, which are very much higher in exchangeable potassium than the three just considered, very different results were obtained. Much smaller amounts of potassium were taken up by these soils from the highest concentration (210 p.p.m. K_2O) and none whatever from the 25 p.p.m. solution.* In fact potassium was given up to the latter solution as is evidenced by the fact that the corresponding leachates contained higher concentrations of potassium than the original solutions. Here, then, the situation is one in which the solution applied to the soil is lower in concentration, although apparently only slightly so, than the equilibrium concentration, and hence leaching of potassium occurs. It is further seen that a potassium solution which leaches this nutrient from one soil, *e.g.* the Aiea or Kailua soil, may give up most of its potassium to another higher sorbing soil, such as the University soil. This relationship is apparent from the data in Table II. As would be anticipated from the foregoing results, the 5 p.p.m. K_2O solutions were greatly enriched with potassium as a result of passing through the Kailua and Aiea soils, the final concentrations ranging from 4 to 8 times the levels at which they entered the soils. The Ewa soil, which is intermediate in exchangeable potassium, proved to be intermediate also in its ability to sorb potassium.

These results indicate the effect which dilution may have upon the sorption of potassium dissolved in irrigation water. Suppose, for example, that 100 pounds of K_2O are applied in 5 acre-inches of mountain water. Ignoring the small amount of potassium naturally present in such water the resulting concentration will be approximately 87 p.p.m. K_2O. Suppose further that this soil is unable to reduce the concentration of the potassium in the water below 25 p.p.m. Then $25/87 \times 100$ or 29 per cent of the applied potassium will remain unsorbed by the soil. Suppose now that the same amount of potassium is applied in 10 acre-inches of water. The resulting concentration will now be approximately 44 p.p.m. K_2O. Since the final concentration will be the same in either case, *i.e.*, 25 p.p.m. the unsorbed portion of the applied potassium fertilizer will now be 25/44 or 58 per cent.

If reference is made to Table II it will be observed that the Kona, Manoa substation, and University soils exhibit a high order of sorption, whereas the Aiea and Kailua soils do not. The Ewa soil appears to be intermediate between the high- and low-sorbing soils. It will be seen by reference to the third column of the table that the exchangeable potassium in the high-sorbing soils is very much lower than it is in the low-sorbing soils, the Ewa soil again occupying an intermediate position. These considerations lead to the conclusion that the quantity of exchangeable potassium in the soil is the primary factor determining whether a potassium solution of a given concentration will add to or subtract from the amount of exchangeable potassium present in the soil. The correlation between sorption and exchangeable

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* In the case of the high-potassium soils, sorption from the second 5 acre-inches of solution was greater than from the first 5 acre-inches. This is probably explainable on the basis that the soils had been air-dried and hence some time was required to re-wet the surfaces of the soil particles and effect maximum sorption of potassium. Probably, also, potassium present in the soil water prior to air-drying crystallized out during the drying process and then dissolved in the first water passing through the soil.

potassium is not perfect in so far as the individual soils within a group are concerned. Thus, in the low-sorbing group, the University soil is seen to contain more potassium than either the Manoa substation or the Kona soils, yet it shows the highest order of retention. Very likely the influence of the degree of base saturation comes into play at this point, the University soil being well supplied with exchangeable bases while the other two soils are very deficient in this respect. As will be shown in a later section the ability of an acid soil to sorb potassium from a given concentration of the salt increases as the degree of base saturation is increased. Hence a soil adequately supplied with exchangeable bases may sorb potassium more efficiently than a more acid soil, even though the latter is somewhat lower in exchangeable potassium. The somewhat greater sorptive power of the Kailua soil as compared with the Aiea soil is probably explainable on the same basis. This factor in the sorption of potassium, however, appears to be of a relatively minor nature as compared with the effect of the level of exchangeable potassium in the soil.

The principles underlying the sorption of potassium by the soil should apply equally to the retention of ammomium salts. The level of ammonium in the soil should therefore be expected to exert an influence upon the sorption of this base. Due to the very small quantities of ammonium in soils, however, this factor can probably be ignored. Although ammonium is considered somewhat less sorbable than potassium, the difference in the levels of these bases in the soil may result in the greater sorption of ammonium. Earlier work of McGeorge (11) supports the view that ammonium is more highly sorbed by Island soils than is potassium.

In order to show further the effect of concentration upon the ability of the soil to take up potassium and ammonium, the following experiment was conducted.* A Hilo coast soil was deprived of its exchangeable potassium and ammonium. It was then leached with large volumes of solutions of potassium chloride and ammonium sulfate, at various concentrations, until the soil could take up no more of these nutrients. The levels of potassium and ammonium thus established in the soils were then determined. The results of this experiment appear in Table III.

Further indications are now seen of the effect of concentration upon the levels of potassium and ammonium in the soil. Thus, for example, the exchangeable potassium which was sorbed by the soil, as a result of prolonged leaching with a solution containing 4,700 p.p.m. K_2O amounted to 14,500 pounds K_2O per acre-foot of soil.† Reducing the concentration of the potassium chloride solution to one-tenth of this value, or 470 p.p.m. K_2O, resulted in the sorption of only about one third of this amount of potassium. Leaching with the lowest concentration employed in the experiment, namely 47 p.p.m. K_2O, resulted in the sorption of only about 1,300 pounds of exchangeable K_2O. Similar results were obtained with ammonium sulfate.

Effect of Degree of Base Saturation (Degree of Acidity):

Reference has been made in the foregoing discussion to the influence of the state of base saturation of soils upon the sorption of potassium. This factor in base exchange will now be considered.

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* A more detailed description of the experimental phase of this test will be found under the heading "Degree of Base Saturation."

† Exchangeable potassium is equal to about 3.3 times R.C.M. potassium.

TABLE III

EFFECT OF CONCENTRATION ON THE SORPTION OF POTASSIUM AND AMMONIUM BY A HILO COAST SOIL

Concentration of potassium chloride			Potassium sorbed		Concentration of ammonium sulfate			Ammonium sorbed	
Normality	p.p.m. K_2O	Lbs. K_2O per acre-inch	M.E./100 gms. soil	Pounds K_2O/acre-foot of soil	Normality	p.p.m. N	Lbs. N per acre-inch	M.E./100 gms. soil	Pounds N/acre-foot of soil
N/10	4,700	1,080	12.3	14,500	N/10	1,400	322	22.8	8,000
N/100	470	108	3.9	4,600	N/100	140	32.2	6.9	2,400
N/1000	47	10.8	1.1	1,300	N/1000	14	3.2	0.4	140

Exchangeable potassium equals about 3.3 times R.C.M. K_2O.

Soils possess definite capacities (base-exchange capacity) to hold acid hydrogen and the various bases. In the sugar cane soils of Hawaii base-exchange capacities range from about 10 to 60 milligram equivalents per 100 grams of oven-dry soil. These soils are therefore capable of holding (in the surface foot) roughly from 7,000 to 42,000 pounds of exchangeable calcium (as CaO), for example, or the chemical equivalent of potassium, magnesium, ammonium, etc. Acids from plant roots, microorganisms, and acid-forming fertilizers together with excessive amounts of water have brought about substantial replacement of exchangeable soil bases by acid hydrogen in many of the soils of the wetter districts of the Islands. In extreme cases, as will be shown in a later paper, this replacement has progressed almost to completion.

Potassium and ammonium, when applied to soils as the chlorides or sulfates, readily replace calcium, sodium, and other bases and are themselves thereby largely prevented from leaching. It has been generally held, however, that these fertilizer salts are able in only minor degree to displace the acid hydrogen of the soil, which is held more firmly than are the bases. If such is the case, then it would be logical to expect that increasing the supply of exchangeable bases in a very acid soil, and thereby decreasing by an equivalent amount the exchangeable hydrogen, as by liming, would enhance the ability of the soil to take up salts of potassium and ammonium. It was therefore decided to vary artificially the exchangeable base content of a soil representative of the more humid districts of the Islands and to measure the ensuing effects upon the ability of the soil to sorb potassium and ammonium.*

A soil from the Hilo coast district of the island of Hawaii was chosen for this study. The soil was adjusted to eight stages of calcium saturation and its ability to sorb potassium and ammonium at each of these levels was determined. The effect of exchangeable calcium upon the ability of the Hilo coast soil to sorb potassium from potassium chloride is shown in Fig. 1. Here it will be seen that, increasing the exchangeable calcium content of a completely unsaturated soil (pH 4.3) resulted in an increased uptake of potassium. The effect was slight with the lowest concentration of potassium employed but very pronounced with the highest. The concentration of this nutrient in the soil water following the application of potassium salts in the field probably varies from values which are higher than those used in this study to values which are still lower. The employment in this study of a hundredfold range in concentrations of potassium chloride should therefore indicate the general effect of increasing base saturation upon sorption of potassium under field conditions. The sorption of ammonium from ammonium sulfate was found to be equally increased by increasing the degree of base saturation of this soil.

These results indicate that both potassium and ammonium replace exchangeable calcium of the soil more readily than they replace acid hydrogen. There seems little doubt, therefore, that increasing the degree of calcium saturation in the more highly leached soils of the high rainfall districts of the Islands might well aid in bringing about increased retention of potassium and ammonium, should this be

* A complete account of this and certain other phases of the work reported in this paper will be found in Soil Science, 51: 265–272, 1941, under the title "Sorption of potassium and ammonium by soils as influenced by concentration and the degree of base saturation."

considered necessary. The substitution of calcium for exchangeable soil hydrogen, however, is not the same thing as simply liming the soil. The former operation would require the most intimate contact between the particles of lime and the insoluble organic and inorganic acids comprising the soil exchange material. Under conditions of Hawaiian sugar cane agriculture, where the normal plowing interval

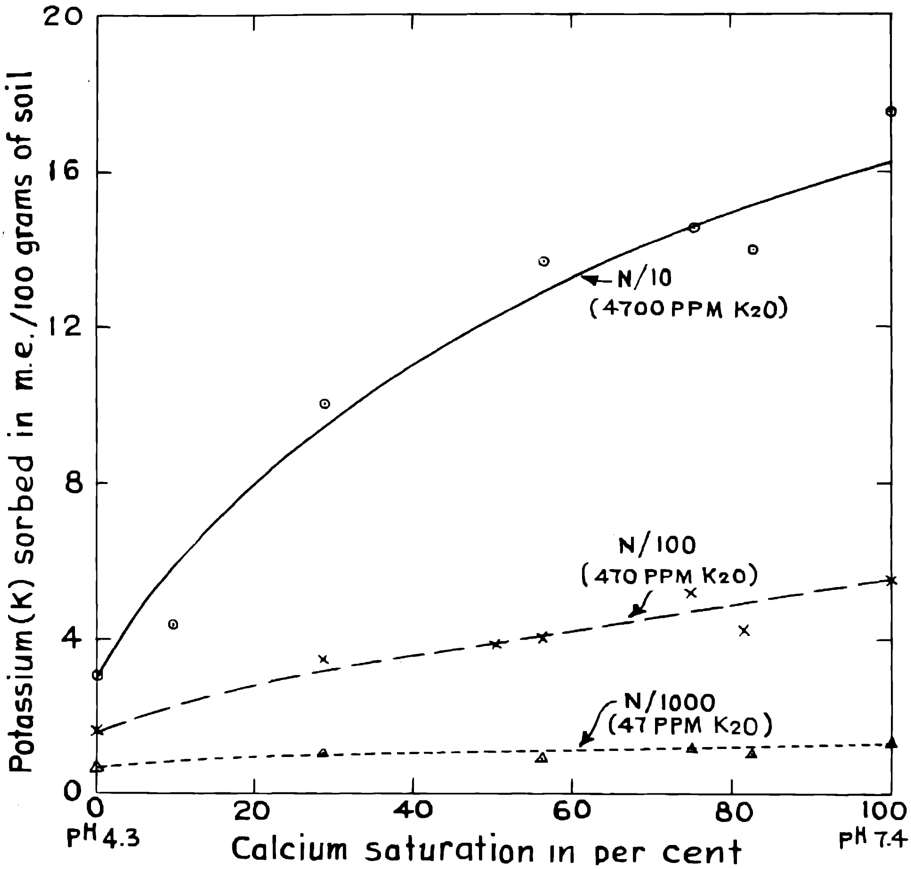

Fig. 1. This figure shows that increasing the exchangeable base content of an acid soil increases its ability to take up potassium from potassium chloride. The effect is seen to be greater the higher the concentration of potassium.

is from 10 to 15 years, such a condition would not be brought about in a reasonable period of time. Brown and Munsell (2), studying the effect of lime upon the acidity of grass land soils, found that a period of 10 years was required, following the surface application of lime to the soil, before a uniform pH was attained in the top 6 inches of soil. The unaided diffusion of calcium through the soil is thus seen to be an extremely slow process.

Effect of the Form of the Fertilizer Salt:

In order to determine the effect of sulfate and chloride ions upon the sorption of potassium and ammonium by very acid soils, portions of the Hilo coast soil

from which all bases had been removed by electrodialysis (pH 4.3) were leached with solutions of potassium and ammonium in both the chloride and sulfate forms. The extent of the resulting sorption of the nutrient bases is indicated in Table IV.

TABLE IV

INFLUENCE OF THE ANION (CHLORIDE AND SULFATE) ON THE SORPTION OF AMMONIUM AND POTASSIUM BY A HYDROGEN-SATURATED HILO COAST SOIL (pH 4.3)

(Results expressed in M.E./100* gms. of soil)

Concentration of salt	Potassium sorbed from		Ammonium sorbed from	
	Potassium chloride	Potassium sulfate	Ammonium chloride	Ammonium sulfate
N/1000	0.7	1.2	0.0	0.2
N/100	1.6	3.4	0.8	3.1
N/10	3.0	10.6	3.3	10.4

* 1 M.E./100 gms. soil equals 1,180 pounds of K_2O per acre-foot of soil *or* 350 pounds of N per acre-foot of soil.

It will be seen that at all concentrations employed, but particularly at the two higher ones, sorption of potassium and ammonium was greater from the sulfate than from the chloride forms of the salts. Such results in the case of acid soils might be anticipated, since sulfates have a slight tendency to render acid hydrogen inactive and thus aid in the sorption of the associated base, whereas chlorides do not possess this property. Recent studies of Koch (8) with Ceylon paddy soils have also shown that ammonium is somewhat more highly retained by soils when applied as the sulfate than as the chloride.

In the above test with the Hilo coast soil, the soil was thoroughly leached with solutions containing relatively large amounts of potassium and ammonium. Subsequent to this experiment, attempts were made to demonstrate differential effects of chlorides and sulfates upon the sorption of the associated bases under conditions corresponding more approximately to normal field practice, with very much larger quantities of soil and relatively smaller amounts of fertilizer salts. Two untreated acid soils were used for these tests, an Aiea soil of pH 5.7 and a Manoa soil of pH 5.0. Under these conditions both the sulfate and the chloride forms of ammonium were sorbed so highly (above 95 per cent) that the anticipated differences were not observed. In corresponding tests with potassium, while there were indications of greater retention of the nutrient from the sulfate than from the chloride form, the differences were not considered great enough for significance. Seemingly then, the effect of the non-basic constituent of the fertilizer salt cannot be expected to be very pronounced on Hawaiian soils where the amount of the salt used is as small, relative to the quantity of soil, as it is in ordinary field practice.

Effect of the Permeability of the Soil:

Hawaiian soils differ greatly in their resistance to the downward passage of water. Irrigation water may remain on the surface of some soils for hours, or even overnight. On other soils it may disappear in a matter of minutes. Soils of

unirrigated plantations likewise exhibit varied resistance to the movement of rain water. The degree to which soils are able to remove fertilizer salts from solutions of these materials percolating through them is dependent in considerable measure upon the length of time the salts and the soil are in contact. If water containing potassium or ammonium passes rapidly through the soil there will be less opportunity for reaction between the salts and the base-exchange material of the soil than would be the case if the downward movement were slow. The results of two tests showing this influence will be found in Table V.

TABLE V

INFLUENCE OF RATE OF PERCOLATION ON SORPTION OF AMMONIUM
(Treatment 250 pounds N from ammonium sulfate in 5 acre-inches of water)

Manoa Soil			Aiea Soil		
Time of percolation (Min.)	Loss of Nitrogen (N)		Time of percolation (Min.)	Loss of Nitrogen (N)	
	Pounds	Per cent		Pounds	Per cent
31	10.5	4.2	16	27.4	11.0
68	4.0	1.6	24	27.4	11.0
150	0.35	0.14	75	12.5	5.0
...	....	....	225	9.5	3.8

The quantities of ammonium "lost" in the present experiment perhaps bear little relation to possible corresponding losses under field conditions, yet they illustrate the effect which the rate of water movement has upon the retentive ability of the soil for this nutrient. Increasing the time of percolation of 5 acre-inches of solution through the Aiea soil from 16 to 225 minutes reduced the ammonium losses from 11 to less than 4 per cent. Retarding the rate of percolation through the Manoa soil made possible all but complete sorption (99.9 per cent) of the added ammonium sulfate.

Summary

A study was made of the influence of the levels of exchangeable potassium and ammonium, concentration, degree of base saturation, form of fertilizer salt, and rate of penetration upon the sorption of these bases by Hawaiian soils. The results may be summarized as follows:

1. Evidence was obtained which indicates that sorption of potassium is primarily dependent upon the level of exchangeable potassium in the soil. Sorption was of a lower order the greater the amount of exchangeable potassium present. This factor can be ignored in the case of ammonium due to the low levels of ammonium in soils.

2. It was found that there is a concentration of potassium for any particular soil above which sorption will occur and below which sorption will not occur. In the case of the soils studied, these concentrations were from 2 to about 30 p.p.m. K_2O.

3. The amounts of potassium and ammonium which soils can sorb from solutions percolating through them were found to increase with increasing concentrations of these bases.

4. Reducing soil acidity by increasing the degree of calcium saturation increased the sorption of potassium and ammonium salts.

5. More potassium and ammonium were sorbed by hydrogen-saturated soil (pH 4.3) when leached with large volumes of the sulfates of these bases than when similarly treated with the chlorides. When unaltered soils containing some bases were treated with amounts of these salts approximating field practice, no differences were observed.

6. Retention of ammonium was found to be higher the slower the rate at which solutions containing this nutrient percolated through the soil.

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Contributions of the Entomologists to Hawaii's Welfare*

By C. E. PEMBERTON

It is quite probable that the original Hawaiians had little or no need for the services of a trained entomologist and, in fact, got along very well without him. Even if we could by some means go back to their days, sensitive and critical as we are, we would hardly find a single insect species sufficiently prominent, annoying or destructive to warrant our wordy abuse. This would not be owing to an absence of insects. Actually there were at least three thousand species, but they were native in a very strict sense of the word. They had been here for untold hundreds and thousands of years. They were settled, balanced, controlled and adjusted to nature's scheme of things in Hawaii to a point where each had its place under the sun and no more, thus constituting what we aptly term "the balance of nature." We know that such a Utopian state actually was maintained amongst the Hawaiian insects at that time. If we go into the undisturbed forests today, these native insects can still be found living in much the same relation to each other and to their hosts as they did long ago. We will find none that can be classed as actual pests. Perhaps the coconut leafroller and the sugar cane leafroller may be listed as pests, but there is some evidence to support the belief that at least the former, which is the worse of the two, is a recent introduction though neither are known elsewhere. (O. H. Swezey recently pointed out to me a statement appearing in Hillebrands' *Flora of the Hawaiian Islands* in which the author remarked that "For a number of years, however, its leaves have been subject to the attacks of a moth which deposits its eggs in the folds of the leaf-segments. Before the caterpillars have entered the pupa stage the young leaves are literally reduced to shreds, which gives to the trees a sad appearance and creates in the occasional visitor the impression that they live under unsuitable climatic conditions." This observation was made prior to 1871 when Hillebrand was last in Hawaii.) There is the strong suggestion here that this leafroller may have reached Hawaii sometime within the past century and is not native.

It might thus be stated as an entomological maxim that those regions, which have had the least change in the species and ecology of their fauna and flora and have been least altered by man over a long period of time, will have the fewest devastating epidemics of insect pests (if any) and the fewest breaks or large shifts in the so-called "balance of nature." However, where these changes have been large and frequent, owing almost solely to the operations of man, insect troubles amongst others become manifold.

Hawaii is one of these places. Here the changes in our flora and insect fauna have been very great within the short period of about 100 years. Almost every

* Presidential address delivered at the Hawaiian Academy of Science, Second Session, Sixteenth Annual Meeting, April 19, 1941.

vestige of the original lowland flora in many places has been swept away and replaced with imported vegetation comprising a long list of plants both desirable and undesirable and with them have come hundreds of insects entirely new to the Territory. Also buildings and streets now cover thousands of acres of land once clothed in native vegetation (such as it was) and even our mountain forest reserves contain an ever increasing variety of introduced plants, some being unwelcome intruders. Changes have thus been profound, and continue; much of the natural equilibrium maintained amongst our plants and animals through centuries of association has been upset. In fact almost everything but the geology of terrestrial Hawaii has changed tremendously since the coming of Captain Cook, and perhaps the geologist will contest even this statement.

From the entomological viewpoint these changes would not have seriously interfered with the affairs of man in the Islands had he not brought with him, unavoidably and unintentionally, a large number of insects new to Hawaii. Many were on or in the plants he brought, while some were in the soil that came with some of the plants. His cows, horses, dogs, cats, poultry and even rats also housed different insects, which enroute from distant lands came ashore with their respective carriers shortly after the early sailing vessels dropped anchor in this Paradise. In the ship's water tanks were mosquito larvae, in other parts were roaches of several species together with bedbugs and other bugs, while in precious seeds and other foodstuffs were weevils and moth larvae and in some of the wood (of course) a termite or two. Some of these insects undoubtedly failed of establishment, but a large number found conditions highly suitable and soon became conspicuous on the landscape. And so today almost every insect one sees about Honolulu, or anywhere outside the native forest areas, is foreign to the Islands and came in as an intruder or was purposely brought in during modern times for beneficial purposes. There are of course a few exceptions.

It is a curious but well-established fact that many plants and animals, when moved away from their own original geographical barriers and placed in a region ecologically suitable, thrive and multiply much better than in their home countries. The prickly pear from America offers a striking case in Australia, where it overran millions of acres before it was stopped with an insect specifically attached to it in America and which controls it there. Fiji has had a similar experience with a so-called weed, *Clidemia hirta,* imported with coffee from Brazil some 50 years ago. It completely swamped valuable lowland pastures and when seen by the speaker in 1920 formed large impenetrable thickets. A South American insect, occurring in Trinidad and living naturally on this weed, was finally introduced into Fiji in 1930 and so completely controlled the plant that when examined again in 1938, original jungles of this pest 6 feet high had disappeared and the land was changed to clear grassy pastures. The insect damage to *Clidemia* had been sufficient to permit other competing vegetation to smother out the hardy immigrant. Lantana is another American plant that thrives and spreads with exceptional rapidity when taken far from home and planted in tropical lands in the absence of its natural insect foes. These cases have many counterparts amongst the insects.

In spite of the fact that Hawaii has some three thousand native species of insects, hardly any are conspicuous or troublesome, whereas all of the real pests are trespassers from other countries and came to us in rather modern times. Why

should the immigrants be pests and the indigenous forms remain innocuous? The partial answer has been expounded so often that it hardly needs repetition. The native species have their own peculiar natural enemies together with other control factors of which we know very little, whereas most of the immigrant pests came without the natural enemies, diseases, etc., which kept them in check in their home lands, and the very limited and specialized Hawaiian fauna offered little or nothing in opposition to them in the form of effective parasites, predators, diseases, etc. This explanation sounds almost too simple to be accepted as fact. Repeated experience has proved the reasoning to be basically sound. With suitable plant hosts present many introduced insects can be expected to multiply prodigiously. Even if their natural insect enemies came with them, such parasites would have great difficulty surviving because of the scarcity of the pest during the first generation. Foreign pests have actually run rampant in Hawaii in a number of cases and in some the very existence of at least one major industry has been seriously threatened. These problems have been solved one by one through recognizing and acting upon the biological facts of natural control just indicated. The results were so gratifying from the very beginning that this method of control has long been standard practice in Hawaii and has attracted world-wide attention. In fact nowhere has the method been so persistently applied with more economically profitable returns.

These highly successful results in the control of insect pests in Hawaii by biological ways were accomplished only because the stage was perfectly set for the application of such a method long before man discovered these Islands, and the stage is still set for further returns, to our benefit, if we continue to apply this system of insect warfare against pests yet out of control. By a set stage we refer to the ease with which many insects can multiply when brought into Hawaii from other parts of the world, and fortunately this applies not only to harmful insects but to beneficial ones also. This makes it possible for the entomologist to accomplish amazing results sometimes.

Insect parasites and predators can usually be expected to work much more efficiently here than in continental areas, providing their hosts are present. There are several reasons for this and they will be different for different insects. For instance the Philippine parasite which we used to call *Scolia manilae* has accomplished a very thorough control of the oriental Anomala beetle on certain Oahu sugar plantations where it became established many years ago, but this same parasite has been repeatedly introduced into New Jersey for control of the same insect—entirely without success. After liberation it disappears and is never seen again. As another instance we mention the avocado mealybug *Pseudococcus nipae*. There was a time when it was a positive nuisance in Hawaii—many trees and shrubs were simply plastered with this mealybug. The speaker has seen avocado trees, guava shrubs and banyan trees about Honolulu positively dripping with honeydew secreted by the myriads of mealybugs on these plants. Park benches in Honolulu where banyans furnished welcome shade during hot days were dirty and sticky from this honeydew. In Mexico where this mealybug is native, it can be found without difficulty, but there it is checked by the minute encyrtid wasp *Pseudaphycus utilis*. When this wasp was introduced into Hawaii it not only checked the mealybug, as it does in Mexico, but went much further. In the opinion of many entomologists in Hawaii today, it succeeded in eradicating the mealybug and in so doing eradicated

itself, since it completely destroyed its own food. It has now been many years since any entomologist has been able to bring to light either the mealybug or the parasite. If this is not control in the fullest use of the word, then what is control? There are many other cases of a similar nature though not so absolute.

So, given the ability to find and introduce the best possible natural enemies of any particular immigrant insect pest, the entomologist of Hawaii will usually succeed famously. We are not making the most of the opportunities this set stage offers us—there is still a great deal to do. Lest we lose faith in the virtues of this biological method, we need to be frequently reminded of some of the triumphs achieved in the past.

Had it not been for the service rendered to Hawaii's sugar industry by entomologists, this large and important business would long since have ceased to exist. This is no idle statement unsubstantiated by facts. The sugar cane leafhopper would alone have eliminated sugar cane as a profitable crop here 35 years ago had it not been brought under control by natural enemies. During 1904–05 and 1906 when it swarmed over the cane fields and not only threatened but brought complete ruin, the combined efforts of managers, chemists and practical field men were absolutely futile in coping with this problem. Insecticidal and other artificial treatment was out of the question because of the expense and insurmountable difficulties of application to thousands of acres of cane jungle. However, a seemingly hopeless situation was in a few years almost completely alleviated following the planters' appeal to two entomologists who were in Hawaii at the time. The planters no doubt felt that they were grasping at a last and doubtful straw. Probably all of you know the history of this case. It demonstrated most clearly that experienced and successful farmers, broadly educated and versed perhaps in many sciences, were in this case absolutely helpless without an intimate understanding and training in the science of entomology. Dr. R. C. L. Perkins and Albert Koebele, to whom the planters appealed for help, were experienced and thoroughly schooled entomologists. They fully understood the facts of biological control amongst the insects, as judged from their own wide experience in the field. Their solution of the problem was clearcut, comparatively simple and accomplished in a reasonably short time at less cost than that of a tourist taking a jaunt across the Pacific to see the wonders of the other side. Perkins and Koebele knew little of insecticides and probably cared less. Their solution of the difficulty was accomplished entirely through natural or biological channels, thus saving a huge industry which otherwise would undoubtedly have fallen into the discard.

This work attracted wide attention. The results were so striking that faith in the ability of the entomologist to work miracles in Hawaii, at little expense, grew rapidly among the men who controlled and developed the major industries of the Islands. Through their support, entomological staffs grew, more miracles were worked from time to time and even today the general feeling prevails that the entomologist can prevent or quickly abate devastating insect epidemics of the future. Generally speaking he probably can. We have the recent case of the taro leafhopper which was well on its way by 1937 toward the complete ruination of taro on Oahu. Costly methods of control or eradication by artificial means were tried and failed most dismally. Realizing the futility of artificial measures, D. T. Fullaway went to the Philippines and in a very short time successfully collected and shipped

to Honolulu the natural enemies which control the hopper in the Philippines. This work effected a complete and permanent control here and the suffering taro plants have returned to their normal and healthful status. One need only talk with the taro planters to be fully convinced that biological methods of insect control can be and are tremendously effective. It is a most remarkable vindication of the parasitic or natural method of checking insect pests in Hawaii. Who but a thoroughly trained entomologist, experienced in the lore of identifying and tracing the origin of insect species, could have accomplished this so quickly—or at all.

Conspicuous among other insect pests of foreign origin, which have been successfully checked by biological methods in Hawaii, may be mentioned the sugar cane beetle borer, the pink and the grey sugar cane mealybugs, the filamentous mealybug (*Pseudococcus filamentosus*), the cottony cushion scale, the sugar cane aphis, the coconut scale (*Pinnaspis buxi*), the fern weevil (*Syagrius fulvitarsis*), the Chinese grasshopper, the mole cricket, and the torpedo bug (*Siphanta acuta*). To a lesser extent many other insects have been considerably checked by imported parasites and predators and the benefits derived have greatly justified the small expenditures of time and money involved. Conspicuous among these are the Mediterranean fruit fly, the status of which has been materially altered since the establishment of several parasites; our two grass armyworms (*Laphygma exempta* and *Cirphis unipuncta*) and several cutworms; the rice stem borer (*Chilo simplex*); the coconut and sugar cane leafrollers; several seed weevils or Bruchidae; and the garden looper (*Plusia chalcites*). These insects do cause annoyance at times and by some residents would be considered still out of control, but the change since their various parasites have been introduced has been very much for the better. In the case of the coconut leafroller, most residents who have been in Hawaii over 25 years will recall the ragged and unsightly appearance of the coconut leaf fronds all about Honolulu which was caused by mass feeding of the caterpillars of this moth. We see very little of this today on the leeward side of Oahu and when it does appear, the oriental parasite *Cremastus flavo-orbitalis* parasitizes a high percentage of the caterpillars. This parasite was unknown in Hawaii prior to 1910. Even the so-called Japanese beetle is now often extensively parasitized by one of the Anomala parasites brought in from the Philippines in 1917. There are also a good many other foreign pests here that have undergone considerable subsidence since parasites have been introduced. Among these are a number of scale insects which are preyed upon by quite a list of parasites of foreign origin.

Very few present-day residents in Hawaii can fully realize or appreciate the extent to which many of our imported pests are actually under control by introduced enemies. This is especially true of those insects which were brought under control a decade or more ago. It is easy to forget the serious damage caused by a pest 20 years ago and fall into the habit of bitterly complaining over some infestation that is actually mild compared with the early difficulties encountered before parasites were introduced.

Control can be economically successful without an approach to eradication. Many of our insect pests are actually under good biological control though they can be found almost any time. The layman is inclined to condemn any so-called control unless it is absolute, whereas he little realizes, without actual experience, the difference between partial control and no control. The grass armyworm *Laphygma ex-*

empta is a good example of this. Periodically, and almost annually, this moth becomes numerous in certain grasslands and on many of the sugar cane plantations. Its caterpillars destroy a large amount of leaf material over a period of several weeks and sometimes several months at a time. But a complex of parasites and diseases ultimately come to the rescue and the trouble rather suddenly stops, the complaints cease, and finally a normal crop of cane is harvested or the affected pasture lands break out in new lush grass. There is of course some loss, but we hesitate to predict what the situation would be if none of these parasites or diseases moved in to stem the tide as the geometrical increase of the armyworm progressed into the fourth or fifth generation.

The sum total of benefit derived continuously from the various useful insects intentionally imported into Hawaii unfortunately cannot be measured in tons of food, in dollars, comfort or pleasure; but it is so large that the cost of maintaining the few entomologists required to build this condition is infinitely small. Once a beneficial insect is established, the gain thereafter is continuous and permanent and the insect requires no further attention on our part.

Biological control programs are by no means always successful. We have had many failures. Sometimes the best efforts of fully qualified men are not crowned with success and there is a long list of beneficial insects introduced into Hawaii which failed of establishment. Of these failures and the work involved, the average resident hears little. Sometimes the insect which failed of establishment was obtained with greater effort and expense than some of the highly successful introductions. Few realize the sacrifices and disappointments which are sometimes the lot of the entomologist engaged in foreign exploration for beneficial insects. However, the fascination of pursuing the unknown is usually ample compensation for most of the failures and there are nearly always a few victories that fully atone for the defeats.

It is not only the men who have actually discovered and introduced these useful insects into Hawaii who have contributed permanently to our welfare. Those on the receiving end have had the extremely important duty of rearing the parasites and excluding the elusive and dangerous secondaries (parasites on parasites), which unavoidably accompany many shipments and which can undo all the potential value of the primary parasites.

There are other important contributors who have participated in this biological control work, who are usually unsung and unrecognized by almost everyone but the men actually engaged in the field work. These are the entomologists composing the comparatively obscure group whose work is purely taxonomic. In the last analysis the parasite hunter is almost helpless until he learns the identity of the insect for which natural enemies are sought. This enables him to immediately consult the world literature and discover what is already known of the insect if it is not a species new to science. But even if it is a new species, the taxonomist will usually be able to throw much light on the world distribution of closely related forms and rather accurately indicate the region where it is probably indigenous. Without the aid of the taxonomist, or access to his published work or well-ordered collections, the parasite hunter must grope blindly like an untrained prospector for oil who has no advance knowledge of petroleum geology to guide him into favorable localities. The museum is the taxonomists' workshop. To the casual visitor it deals with

things dead and of the past, but to our parasite hunter setting out on his trail, it throbs with material of immediate and practical value.

The building up of museum collections of insects, involving the identification, ordering and maintenance of thousands of specimens, is a slow and exceedingly laborious process. The insects are not simply specimens on pins put away in boxes to idly amuse visitors by their curious shapes and beautiful colors. The minutely and carefully lettered labels attached to every pin are as valuable to the collection as a track to a railroad train crossing a continent. As every entomologist knows, a pinned insect without a label, telling at least when and where it was collected, is comparatively worthless. Someone has said "A pinned insect without a label is of less value than the label without the insect."

The unending and tedious work of pinning, labeling and identifying the thousands of insects housed, let us say at the Bishop Museum, is a contribution to Hawaii's welfare of large proportion. It embraces the work of not only the Museum entomologists but also of specialists all over the world. The collection tells us almost at a glance a great deal about the species of insects scattered over the Pacific Ocean and particularly Polynesia.

Twenty years ago the speaker had occasion to utilize in a very striking way and with economic benefit to us in Hawaii, the meagre data included on an insect label in an obscure collection of insects in Australia. A fern weevil, *Syagrius fulvitarsis,* definitely foreign to Hawaii was devastating the beautiful Sadleria ferns of the Kilauea forest reserve on the island of Hawaii. It had been in the Islands a good many years. Entomological literature, museum collections and weevil specialists were consulted to determine, if possible, the source of this pest—but without avail. There were no apparent records of its occurrence anywhere outside Hawaii excepting under artificial conditions in greenhouses in Sydney, Australia, and Dublin, Ireland. Nor were any related species known anywhere. Without a clue to its origin there was little hope of finding efficient or specific natural enemies for it. Local parasites in Hawaii took no interest in it and there was justifiable fear that the weevil would ultimately eradicate large areas of fern cover in our important forest reserves to the great detriment of many of the native forest trees, highly sensitive to such an ecological change.

Purely by chance a single specimen of this weevil was found in an old and private collection of insects in Sydney while the speaker was in Australia engaged in another pursuit. The old and faded labels on the pin, which held the beetle, released the secret for which entomologists had been searching for many years. The specimen had been collected in a forest area in New South Wales in 1857 by an entomologist named French. The labels read "Wien Wien, Richmond River, New South Wales, 1857, French." The few moments French gave to pinning this beetle, attaching the labels and storing it in a box to be placed in a small museum, was a contribution of great value of which he little dreamed. Sixty-five years later the specimen gave us the necessary clue to the original habitat of the species—the rest was simple. Some of the forest region indicated on the label was found to be still in its original, pristine condition, though circumscribed by farms. The weevil, though very scarce, was soon found amongst some of the ferns and its larvae were well parasitized. Within a few weeks the parasite had been shipped to Kilauea and established. Satisfactory and permanent control of the pest followed.

This exemplifies in rather spectacular fashion how museum collections of insects can be of permanent economic importance and may serve usefully at unexpected times. During the past thirty years extensive collections within the Pacific have been made by entomologists financed with Hawaiian capital. These are contributions of great value to the future. Much of the material is deposited in the Bishop Museum. Other large collections, which are invaluable for immediate reference when needed, can be found at the Board of Agriculture and Forestry and the Experiment Station, H.S.P.A. These are being frequently added to. Recently extensive additions have been made through foreign exploration and collection within the Pacific by Messrs. Swezey, Zimmerman and Williams. With the great increase in travel over the Pacific by commercial and naval steamers and airplanes, danger of new pests reaching our shores in spite of quarantine restrictions is rapidly growing. These collections are thus becoming contributions of greater and greater utility for reference purposes. They constitute vital aid to the solution of future problems in the biological control of new pests which we cannot anticipate at present. Such collections have many other uses which we will not discuss here.

There are other fields of endeavor in which entomologists of Hawaii have served the Territory with great credit to themselves and the profession. For many years the pineapple industry suffered great losses from a malady to the plants now designated as "mealybug wilt." The establishment of proof that the mealybug *Pseudococcus brevipes* was responsible for this particular kind of wilt, and the development of highly effective artificial measures for control of this insect have been contributions of huge monetary value to the industry and the Territory.

Thirty years ago mainland markets were closed to most Hawaiian fruits and vegetables because of Federal and State quarantines erected against this Territory to prevent the Mediterranean fruit fly and melon fly from spreading to the California coast and beyond. This has had a considerable effect in discouraging diversified agriculture here. Recently entomologists of the Fruit Fly Laboratory of the U. S. Bureau of Entomology and Plant Quarantine in Honolulu have perfected processing methods which render Hawaiian fruits and vegetables safe for shipment to the mainland. As a result the quarantines have been modified and new markets have been opened for products which have long suffered the heavy handicap of a quarantine barrier. It is possible that this may ultimately lead to prosperity for many of Hawaii's small farmers.

Little has been accomplished in the past to perfect insecticidal control of many insects which attack and often ruin some of our food crops and ornamental plants. Small gardeners have struggled against great difficulties and have had little constructive help or advice in problems that are strictly within the field of entomology. In recent years this situation has been improved with the reorganization of the department of entomology at the University of Hawaii and with the appointment of an entomologist and horticulturist at the Hawaii Agricultural Experiment Station.

A valuable service contributed by entomologists of the Territorial Board of Commissioners of Agriculture and Forestry, which is apart from insect control, has been the development of a completely satisfactory and practical method of chemically protecting wet-land taro of Oahu against an imported crayfish, which only a year or so ago marched through much ~~of~~ our taro lands with disastrous effects.

Another branch of the Board, the Division of Plant Quarantine, is primarily a service staffed by entomologists, and it has long been absolutely essential to Hawaii's welfare. As proof of the effectiveness and value of this service to the Territory, it is only necessary to state that the great majority of our most pestiferous insects gained entrance to these Islands before the Division of Plant Inspection was thoroughly organized.

In many ways entomologists have thus found useful work to do in Hawaii. They should be as much in demand in the future as in the past. The community will expect and probably receive entomological aid over a still wider field than at present. Staffs should be increased wherever possible, since it is not likely that the calls for assistance will decrease.

But in any plans for the future the greatest and most permanent good, for the largest number of people at the least expense, will almost certainly come from continued exploration and research in biological control. Without question most money already spent in this branch of entomology has paid handsome dividends and continues to do so. We should not be content to rest on our laurels and assume that the best to be had of beneficial forms are already here. There are still large and promising fields in the realm of beneficial insects open and waiting for our investigation. If we are to make the most of the opportunities so offered, one or more field laboratories in specially selected foreign regions, continuously operated by rotating entomologists from Hawaii and financed by local institutions, public and private, should be maintained. The cost of keeping entomologists in the field is hardly greater than if they are kept at home, excepting where all living expenses are paid by the employer.

Some years ago a prominent and successful Honolulu business man, having full knowledge of the part biological methods played in the control of some of our worst pests, suggested in conversation with the speaker, that Hawaii would be better off if most of the well-trained entomologists who live in Honolulu were to reside and draw their salaries in some foreign country instead of here at home. It was his opinion, strongly put, that no entomologist could find or conjure a new and useful insect in Hawaii unless it were already here and that at least he ought to spend some of his time in foreign tropical regions where even chance alone might bring to his attention insects potentially useful for these Islands. His reasoning was perfectly sound. It has been the common experience of entomologists engaged in biological control investigations in foreign countries to find many useful parasites and predators of which they had no prior knowledge. We could even name a good many beneficial insects already recorded in foreign countries which would be very well worth trying here.

The work of Albert Koebele furnishes a beautiful example of what we can expect from capable entomologists placed in rich entomological fields, free to roam and investigate at will, with no special and hampering obligations other than the broad problems assigned them. Koebele had special assignments, but he seemed to carry all of Hawaii's insect troubles in his mind as he wandered in foreign countries. Many of the beneficial insects in Hawaii today were observed and introduced by him during many years of travel in China, Japan, Ceylon, Australia and Mexico. He was sufficiently familiar with our insect problems to know when he came across an insect that might be useful here. The sum total of his miscellaneous introduc-

tions is of very great value to this Territory. Much that he found was undoubtedly new to him, since literature in those days could have only served as a poor guide to what he might expect. He found these useful insects only because he was in the right field and was qualified and enthusiastic for work he must have known would pay. There are a good many entomologists in Hawaii now who have done the same sort of work and are fully capable of doing more of it. If staffs are maintained as they are today, there will always be a sufficient number of men to handle both the home and foreign work. There are no special or serious problems at present, but we should not wait for some serious emergency to stimulate us to further importations of beneficial insects.

Returning again to our business man who would like to see more of Hawaii's entomologists living far away but still on our payrolls, the question was asked, "Where can we expect to find the greatest assembly of beneficial insects adaptable for use in Hawaii?" Without question the natural zoogeographical region classed as "Oriental" would best suit us. This region embraces India south of the Himalayas, Southern China, Malay Peninsula, Sumatra, Java, Bali, Borneo and the Philippines. To this must be added much of the Australian region also, which includes Australia and the rest of the Malayan Archipelago not already mentioned. In the Australian region we will find New Guinea and some islands to the west particularly fruitful. It is this part of the world, south and west of us, that gave origin to a great deal of Hawaii's native insect fauna and, curiously enough, much of our man-imported pest fauna came from there also. As already indicated several times, it is in these places of origin that the greatest number of natural control factors will be found. The maintenance of a so-called parasite laboratory in Ceylon, the Federated Malay States or the Philippine Islands for several years would unquestionably pay for itself many times over, if continuously staffed with a few of our qualified men. An entomologist's laboratory to serve the particular purposes required in the present suggestion need consist of hardly more than a few microscopes, a proper assortment of glassware and a few other simple tools of the profession, all housed in a room or two. It is not the laboratory that is essential. Entomologists today can usually conduct such work near centers of civilization where museums, libraries and contemporary scientific workers can be found. We suggest Kuala Lumpur, Federated Malay States, as approaching the nearest to an ideal locality for our foreign parasite laboratory. It is not only here that entomologists have lived and worked for many years and built up a splendid and well-ordered entomological collection, but the country is one of the richest in the world with respect to fauna and flora, and now lies in point of time by air mail, fairly close to Hawaii.

To mention a few of Hawaii's insect pests which occur naturally in Malaya, or have their close counterparts and which most probably have parasites or predators there of importance which we need in Hawaii, the following are listed:

The sweet potato stem borer (*Omphisa anastomosalis*). The larvae of this moth seriously damage the stems of sweet potatoes and may even bore down into the tubers. Parasites are badly needed and probably could be found in the Indo-Malayan region where this insect is known and is almost certainly native. The rice borer *Chilo simplex*, belonging to the same family of moths and of Oriental origin, has been investigated by Hawaiian entomologists in the Orient. Parasites were

found and introduced into Hawaii. One of them which became established has also taken to this sweet potato stem borer and is doing some good on Oahu. This serves to show that other and probably more specific parasites of the stem borer could be found if search were made for them. We hear a great deal these days about the utility of the sweet potato as a source of food in Hawaii in case of an emergency. In the event of large plantings, maintained over a considerable period of time, we can expect this borer, as well as some other of the sweet potato insects, to become very important pests of this crop and production may be seriously curtailed.

Our cone-headed, pink-winged grasshopper *Atractomorpha ambigua* is of Oriental origin. Species of the same genus occur in Malaya. Though parasites and other natural enemies are unknown, careful exploration has not been made in this field and the chances are good that such could be found. Our green grasshopper, which we call the Chinese grasshopper *Oxya chinensis,* was not known to have parasites in Malaya until we investigated it during 1930 and found parasites which now satisfactorily check it in Hawaii. This suggests that parasites could probably also be found for *Atractomorpha.*

Both the coconut leafroller *Omiodes blackburni* and sugar cane leafroller *Omiodes accepta* are unknown elsewhere, but there is every indication that they, or rather their ancestors, are of Indo-Malayan origin. Parasites of related forms in Malaya or India should be introduced into Hawaii and tried. The best we yet have for these moths is the Oriental wasp *Cremastus flavo-orbitalis.*

The hibiscus white fly *Aleurodes hibisci* has long been considered a native of Hawaii. It is often so abundant on certain varieties of hibiscus as to suggest that it is of foreign origin. A few years ago we learned that it occurs in Formosa, where it is said to be rather uncommon. This strongly suggests an Oriental origin and offers another nice opportunity for the traveling entomologist to accomplish a useful work in biological control.

The rose beetle or Chinese beetle *Adoretus sinicus,* commonly known here as the Japanese beetle, is definitely from the Oriental region. It is known in southeast Asia, Java, Timor and Formosa. This and related species can be readily found in this general region and are known to have a number of natural enemies, some of which have already been tried on Oahu without success. It does not appear that parasites of importance will be found until investigators have opportunity to live in the natural field of activity of this pest and its closely related cousins for a considerable length of time and have a free hand to thoroughly study and determine its natural enemies.

The mango weevil *Cryptorhynchus mangiferae* is known to occur all the way from Africa, through Indo-Malaya into the Philippine Islands. It is perhaps native in the Oriental region and should have some natural enemies, though none are recorded. It does not seem to be nearly as important there as in Hawaii. We suspect the reason no parasites are recorded is because little attention has been given to the subject outside of Hawaii, since it is unimportant elsewhere as a mango pest. Certainly the beautiful mangoes of the Philippines are much less affected by this weevil than are the mangoes of Hawaii. We should try and determine the reason.

There is a pretty little bluish-purple butterfly *Cosmolyce boetica,* with a wingspread of about an inch or more, whose larvae feed in the pods, seeds and flowers

of a large number of our leguminous plants. It is a pest of importance in these Islands and has been known here for at least 60 years. It is believed to have come originally from some part of that portion of the world lying between Africa and Japan and is known all the way between. Natural enemies of importance probably occur within the Indo-Malayan region and should be easy to obtain by any capable investigator. Dr. Williams has recorded one parasite which occurs in the Philippines.

The cabbage webworm *Hellula undalis* has been in these Islands at least since 1892. It is known in Indo-Malaya but is considered of minor importance there. The reason for this comparative scarcity should be determined and can only be accomplished by an entomologist living with the problem for a considerable length of time. Effective natural enemies of any insect fluctuate in abundance through the year and there are times when it might be difficult or impossible to obtain them, even where they may be accomplishing the greatest good.

To mention a few more: The koa seed worm or litchi borer *Argyroploce illepida* has a number of host plants in Hawaii, but it particularly damages litchi fruits, macadamia fruits and the seeds of *Acacia koa*. Mr. Swezey has shown that from 50 to 90 per cent of the koa seeds are often destroyed by this insect. It is known in the Oriental region and is probably well parasitized. Several parasites have been mentioned as attacking it and in southern China the litchi is said to be only lightly damaged by this worm.

The lima bean pod borer *Maruca testulalis* is a lima bean pest of major importance. It has only been known in Hawaii for about 19 years. It occurs in Indo-Malayan countries where it is not particularly destructive. It is listed as an insect of minor importance. At least one parasite is known to attack it in India. Parasites are much needed for it here.

Our most abundant cockroach is probably *Diploptera dytiscoides*, the so-called beetle roach. It is also called the cypress roach. There are times when it will mass in trees and other shrubbery or in trash on the ground by the thousands. It damages cypress trees through girdling the tender branches, which kills them and often renders the trees unsightly. Occasionally it has become so thick in the gardens at Waikiki and Kahala that residents complain. It is not a serious pest, but it can be a distinct nuisance. It is just another case of an insect living far from its natural home and hereditary enemies. It is known in Malaya, New Guinea, India and adjacent countries, where it seems to be comparatively uncommon. We should know why. It undoubtedly has natural enemies which would be useful in Hawaii, but they will probably never be found unless we search for them, since the roach bothers no one outside of these Islands.

And finally mosquitoes. What a host of natural enemies feed on mosquito larvae and pupae and how few we have in Hawaii. Our most important are the mosquito fish, but there are other enemies to be had that can operate where the fish cannot go. Many of these enemies are otherwise harmless and should be tried here. While the speaker was in Malaya during 1930 the scarcity of mosquitoes at night was immediately observed in some localities where they would be expected to be abundant. Mosquito nets covered beds almost solely for the purpose of keeping out stray malarial mosquitoes. Annoying hordes of other species were not in evidence, though small numbers of many species were always around. Natural enemies in the

form of insects which prey on the mosquito larvae and pupae were numerous in every pool or pond examined. Some of the best of these should be imported into Hawaii at frequent intervals until they become established, or at least have been given a good trial.

These are sample cases of what might be accomplished in further biological control of some of our insect pests, if we established as a first experiment a field biological laboratory in Malaya. There is every reason to believe it would be worth while. Unquestionably we need more beneficial insects and as diversification in agriculture gains headway, resulting in the extension of old crops and probable development of new ones, further insect problems are bound to arise and unless solved will surely limit the productivity of necessary food crops otherwise well adapted for culture in these Islands. The development of effective insecticidal control of some of our economic insect pests is necessary especially during emergency periods, but such procedures are expensive, especially in Hawaii and of course only temporarily effective. Without satisfactory biological control of certain insect pests some crops might be abandoned because of prohibitive costs in their control by artificial measures. The recent taro leafhopper trouble, already mentioned, is a good example.

In Dr. Walter Carter's Presidential Address to this Academy two years ago, the possibility of greatly extending our agricultural wealth through the development of many new crops or industries related to these crops was strongly indicated. The future of some will very probably depend upon the degree to which some of their insect pests, already here, can be controlled. Biologically considered, we are still isolated from the rest of the world almost as much as ever and the need for entomologists may be as great in the future as in the past. We hope, and believe, that they will meet the problems of the future in the same way, and as successfully, as they have during the past 30 or more years, and that, in the light of experience, the biological method will continue to command the faith and receive the attention that it justly deserves.

Some Observations on the Fluctuations of Moisture Content in the Sugar Cane Plant

By H. A. Wadsworth

Although the literature of investigations on the sugar cane plant gives occasional references to the moisture contents of the plant tissue, detailed studies of daily or hourly changes in this property are conspicuously infrequent. In general the results given have been secured for special purposes and do not lend themselves to interpretation in terms of changes of moisture content with respect to time. An outstanding exception is Hartt's (2), (3), (4), (5) determinations in connection with her studies of water and cane ripening. Here the times of sampling are definitely specified and give some evidence of diurnal changes of internal moisture contents which may be of great importance in the sugar economy of the plant.

Das (1) has suggested that photosynthesis, which takes place during the period of decreased moisture content in the plant tissue, is associated with, and possibly responsible for, an increase in the percentage of recoverable sucrose in the cane plant. Observations (11) on the percentage of total sugars secured from growing cane in Field B-4, Pioneer Mill Company, indicated a significant fluctuation in this value during a 24-hour period. Although the consistently high percentages of total sugars, reported late in the afternoons when the hand refractometer was used, may be caused by an accumulation of sugar during the day, it would appear more probable that such an effect results in part from a temporary depletion of moisture in the tissues sampled. The fact that the Brix falls during the night adds support to this conclusion. Similar observations at the variety station at Hilo failed to disclose any such diurnal variations in percentages of total sugars during the 24-hour cycle. Apparently the transpirational demand at Hilo did not require a withdrawal of water from the stick with concomitant concentration of sugars.

The evident relationship between these observations upon Brix variations at Lahaina and Hilo, the reputations of the two locations for quality ratios and Das' suggestion may prove to be the turning point in our better understanding of some of the factors involved in economical sugar production particularly when irrigation is resorted to.

Moisture Contents in Growing Cane

As has been suggested, Brix values within short time intervals may be assumed to be closely correlated with the moisture in the tissues sampled; a more direct measure is, of course, the actual determination of the moisture content by oven-drying procedures. Unfortunately such determinations require the destruction of the plant; consequently they are infrequently done.

Opportunities for making such determinations were available, however, at Waipio in conjunction with Experiment 104-I, the results of which have been re-

cently reported (12). The results support the conclusions drawn from the Brix studies. They are given here to complete the record.

Moisture Percentages on the Wet Basis and Dry Basis

Losses of water by oven drying are best reported as percentages of some specified quantity. This may be either the weight of the green tissue which is weighed into the drying tins or the weight of the oven-dried tissue remaining in the tins after exposure to the heat of the oven.

If the weight of the green tissue is used as the basis of per cent loss, the result is said to be reported on the wet basis.

If the weight of the oven-dried tissue is used as the basis of per cent loss, the result is said to be reported on the dry basis.

If T = weight of oven-dry tissue involved,
W = weight of water associated with that tissue,
then (T + W) = weight of green tissue,

$$\text{and } \frac{W}{T} \times 100 = Pd = \%\text{ moisture (dry basis)}$$

$$\frac{W}{(T + W)} \times 100 = Pw = \%\text{ moisture (wet basis)}.$$

It is evident that the percentage of moisture on the wet basis can never exceed 100 per cent; it is also evident that the percentage on the dry basis may approach infinity.

The relationship between Pw and Pd may be expressed:

$$Pd = \frac{Pw}{1 - \frac{Pw}{100}} \ *$$

This equation is perfectly general. For example: a sample of cane stick weighs 120 grams when wet and loses 100 grams on oven drying. The percentage loss on drying is $\frac{100}{120} \times 100 = 83.3\%$ (wet basis). On the dry basis the loss is still 100 grams, but the denominator in place of being 120 grams is 20 grams, and the percentage of moisture is $\frac{100}{20} \times 100 = 500\%$ (dry basis).

We secure the same result by substituting in the simple equation,

$$Pd = \frac{83.3}{1 - 0.833} = \frac{83.3}{0.167} = 500\%$$

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* $\frac{W}{T} \times 100 = Pd$

$W = \frac{PdT}{100}$

$\frac{W}{W + T} \times 100 = Pw$

$W = \frac{PwT}{100 - Pw}$

$\frac{PdT}{100} = \frac{PwT}{100 - Pw}$

$Pd = \frac{100\,Pw}{100 - Pw} = \frac{Pw}{1 - \frac{Pw}{100}}$

It is to be noted that a moisture percentage of 500, on the oven-dry basis, means that each pound of oven-dry tissue in the stick is associated with five pounds of water.

Either of these two means of expressing moisture percentages is perfectly permissible, but their interpretation should not be confused. If a quantitative measure of the water lost from a tissue is desired, the percentage as expressed on the oven-dry basis must be used. As in other fields of physical measurements the unit selected should be the one which is to remain as nearly constant as possible. In our case this is the weight of oven-dry tissue. Although this value is not absolute and may perhaps be questionable because of increased weight through synthesis during the short periods under observation, it is to be preferred to the green-weight basis which changes with every change of moisture content.

For some purposes and within certain percentage ranges, it is unimportant which of these bases is used for expressing moisture percentages. But the differences become greater as the percentages of moisture increase. Table I indicates the relationship between these quantities as determined from the equation given above.

TABLE I

RELATIONSHIPS BETWEEN PERCENTAGES OF MOISTURE ON THE WET BASIS (Pw) AND CORRESPONDING PERCENTAGES ON THE DRY BASIS (Pd)

Pw	Pd	Pw	Pd
0	0	70	233.0
5	5.3	80	400.0
10	11.1	85	566.0
20	25.0	90	900.0
30	42.9	95	1900.0
40	66.6	99	9900.0
50	100.0	100	Infinity
60	150.0		

By dividing each of the values given under Pd by 100 we obtain the number of grams of water associated with each gram of oven-dried tissue. For example, if the moisture percentage of a sample is 85 per cent on the wet basis, each gram of oven-dry tissue in the material sampled holds 5.66 grams of water. If the percentage of the material on the wet basis falls to 80 per cent, each gram of the material holds 4.00 grams of water. Each gram of the material has lost 1.66 grams of water while its moisture percentage on the wet basis falls from 85 per cent to 80 per cent. These ratios hold, of course, whether the units be grams, pounds or tons. In view of the large amount of dry material in a cane field and the high moisture percentages on the wet basis, it would appear that water from this source might contribute significantly to the daily needs of the crop. When adequate soil moisture is available, we would expect a restoration of moisture content in the tissue during the night with a falling off in the rate of loss by transpiration. Apparently we had some such effect with sugar cane at Pioneer Mill Company.

Diurnal Moisture Fluctuations in Sugar Cane at Waipio:

Studies directed toward the determinations of the actual changes in moisture content in sugar cane growing in the field were begun at Waipio in October 1940.

The first test was planned to gain a measure of the variability of the material available for random sampling. Cane from Field 28, variety H 109, age 12 months, was used.

Two lots of samples were taken. One of these taken at 2:00 p. m. on October 25 was supposed to represent the moisture content in the cane when the withdrawal of water from the tissue was advanced but possibly not completed. Another set of similar samples was taken at 6:00 a. m. on the following day. Supposedly the moisture deficiency impressed upon the plant by rapid transpiration during the day of October 25 would have been eliminated during the night. It is believed that the soil moisture was above the permanent wilting percentage at the time.

Fifteen sticks were cut close to the ground at each time of sampling. Samples of the dry-leaf cane, the leaf sheaths and the growing points were quickly secured, weighed to the nearest 0.01 gram in tared cans and dried to constant weight at 85° C.

Samples for the leaf sheaths included material from the sheath associated with the last visible dewlap and from the three sheaths immediately below it. The growing point was removed from its wrapping of succulent material before weighing. These samples were about one inch long.

All samples were treated separately. The averages and their probable errors are listed in Table II.

TABLE II.

AVERAGE MOISTURE CONTENTS IN PER CENT (DRY BASIS) OF SUGAR CANE STRUCTURES COLLECTED AT 2:00 P. M. OCTOBER 25 AND 6:00 A. M. OCTOBER 26, 1940

	Morning Oct. 26	Afternoon Oct. 25
Growing Points	962 ± 12	871 ± 19
Sheaths	437 ± 8	390 ± 7
Millable Stick	416 ± 7	385 ± 5

Although these differences are not large, they may be considered as significant and are in the direction anticipated.

Such evidence as that given in Table II suggests a cyclic action characterized by high moisture contents before daybreak and low moisture contents late in the afternoon or early evening. An attempt to explore this possibility was made in a sequence of samples secured from the same area at three-hour intervals between 9:00 a. m. November 22, 1940 and 6:00 a. m. November 23, 1940. Limitations of equipment made it necessary to reduce the number of samples to four sticks taken at random at each time of sampling. The variability noted at the time of the first sampling, and reported in Table II, tended to obscure the details of the suggested cycle. Results are given in Table III for the sake of completeness of the record. Average values alone are reported; the limited number of samples taken precludes any satisfactory measure of variability. Apparently the number of samples was inadequate.

TABLE III

MOISTURE CONTENTS OF CANE STRUCTURES AT VARIOUS TIMES OF THE DAY (DRY BASIS)

Hour	Growing point	Sheath	Millable stick
9 a. m.	890	366	393
Noon	916	451	408
3 p. m.	832	397	342
6 p. m.	960	444	393
9 p. m.	950	386	370
Midnight	923	406	376
3 a. m.	991	448	395
6 a. m.	1065	471	375

Apparently the diurnal cycle of moisture contents, if it exists, could only be plotted in detail if many more samples were taken than were available during the test reported in Table III. Moreover, if this diurnal sequence is a result of transpirational demands in excess of the possible rate of supply by the roots, its appearance might not be marked in November.

An additional series of determinations of moisture contents in growing points was made on November 4 and 5, 1940. For this test sticks were cut from a stand of two-year-old cane which had been trained to stand erect at the Keeaumoku Street Station. The canes were about 20 feet tall. Ten sticks were cut and growing points removed at 4:30 p. m. on November 4; a similar collection was made at 6:00 a. m. on the following morning. Although the average values for the moisture contents were numerically different in the sense that the afternoon samples were drier than those secured in the morning, the difference was not statistically significant. The average values were as follows:

4 p. m. Samples	673 ± 33% (Dry Basis)
6 a. m. Samples	714 ± 36% (Dry Basis)

It is to be noted that these average values of moisture content in growing points are associated with evidence of high variability. The same characteristic was noted in the results from the first series of growing-point samples at Waipio, reported in Table II. In searching for a cause for this great variability, it was observed that low values for the percentages of moisture content were associated with samples of high weight after oven drying. The correlation coefficient between moisture percentage and oven-dry weight at the time of the morning sample was -0.82 ± 0.11. The correlation coefficient between the same variables for the afternoon sample was -0.88 ± 0.08. Such high degrees of correlation are at least suggestive.

Since the amount of tissue taken was not uniform, it seems probable that the heavier samples, after oven drying, were originally longer and included more relatively dry tissue below the actual tip. When the points representing these two series of variables are plotted and fitted with straight lines, both lines intersect the zero weight axis at a percentage of about 1000. Apparently the tip of the growing point carries almost 10 grams of water for every gram of oven-dried tissue. And too, this value seems to be independent of the time of day in contrast to the evidence of day-time desiccation in other tissues.

This single observation is inadequate as a basis for generalities. However, it

might be reasoned that there is evidence that a distinct gradient in moisture content exists in the top of the cane stick. Moreover, it might appear that a constant moisture was maintained in the apical meristem if possible, even if other tissues suffered partial desiccation during the day.

Moisture Determination by Other Workers:

In an early report on "Water and Cane Ripening" Hartt (2) gives moisture percentages for blades, sheaths and green-leaf cane. Half of the plants in the study were suffering from inadequate soil moisture; half had an adequate supply. Each of these lots was divided again. One half of each had been held in the dark until the time of sampling; the other half was removed to the greenhouse and had experienced seven hours of sunlight after a long period in the dark. The four series were called "Dark dry," "Dark wet," "Light dry" and "Light wet."

Moisture percentages as reported are given in Table IV.

TABLE IV

MOISTURE PERCENTAGES IN CANE PLANTS SUPPLIED WITH OR DEPRIVED OF WATER. (AFTER HARTT [2])

	Blades	Sheaths	Green-leaf cane
Dark dry	67.89	79.63	84.36
Dark wet	70.72	85.21	88.52
Light dry	66.64	76.30	84.16
Light wet	69.57	84.20	87.83

The percentages given in Table IV are on the wet basis. To indicate the actual amount of water involved, these percentages should be changed to the corresponding values on the dry basis. This is done in Table V.

TABLE V

MOISTURE PERCENTAGES IN CANE PLANTS SUPPLIED WITH OR DEPRIVED OF WATER (DRY BASIS)

	Blades	Sheaths	Green-leaf cane
Dark dry	211	392	539
Dark wet	242	577	772
Light dry	200	321	531
Light wet	228	536	721

Since the percentages reported in Table V are given on the dry basis, differences in values represent masses of water associated with unit masses of dry tissue. Thus sheaths on dry plants in the dark held 3.92 grams of water per gram of dry matter. After 7 hours exposure to light each gram of dry tissue held 3.21 grams of water. Apparently 0.71 gram of water had been withdrawn from each gram of this tissue during the seven hours. During the same interval only 0.08 gram had been lost from each gram of green-leaf cane.

The weights of water lost from these tissues and ~~others~~ during the seven hours of exposure to evaporating conditions in the greenhouse are given in Table VI.

TABLE VI

LOSS OF WATER IN GRAMS PER GRAM OF OVEN-DRIED TISSUE DURING 7 HOURS OF GREENHOUSE EXPOSURE

	Blades	Sheaths	Green cane
High Soil Moisture	0.14	0.41	0.51
Low Soil Moisture	0.11	0.71	0.08

Apparently during periods of readily available soil moisture the green cane and sheaths lost most heavily when the plants were exposed to the environment of the greenhouse. In the case of the dry series the major contribution was made by the leaf sheaths.

Similar studies were reported by Hartt in 1936 (3), (4) and 1939 (5). Results were comparable to those reported above. In all cases there was a marked fluctuation of moisture content in the sampled parts during the 24-hour period involved.

In discussion of the variations of moisture content within the plant tissues in one of these reports (4) the statement is made that "It would seem that the moisture content of the sheaths is affected by the time of day less than is the moisture content of the blades." The sheaths in one case vary from 79 per cent to 81 per per cent (wet basis) ; the blades from 67 per cent to 70 per cent (wet basis). Here we have a loss of 3 per cent from the blades and 2 per cent from the sheaths. If these percentages are translated into figures on the dry basis, which alone permits comparison, the sheaths vary from 377 per cent to 425 per cent, the blades from 202 per cent to 233 per cent. Apparently each gram of oven-dried material in the sheaths contributed 0.48 gram of water during the desiccation while the blades contributed 0.31 gram of water per gram of oven-dried material.

Although the total mass of sheath tissue associated with a cane plant is small in comparison with the total, such tissue seems to have an outstanding capacity to acquire water when available and to supply it upon demand.

Further evidence (10) of the delicate relationship between leaf sheaths and soil moisture contents comes from a study of the length of sheaths produced on the Waipio experiment (12) which has been mentioned. Frequent collections of the sheaths produced under the various treatments demonstrated that sheaths were definitely shorter when produced under a history of repeated soil moisture deficiency, than when produced under such frequent irrigation that moisture was always readily available. This difference tended to disappear as the crop became older possibly because of increased length of stick below the green top. One explanation for the shorter length of sheaths from plants which had experienced frequent periods of drought is to assume that the desiccation of this tissue was so frequent and so intense that maximum length could not be secured before structural maturity was attained.

Subsequent observations upon the lengths of the cane joints formed under the several treatments gave analogous results. Joints formed in the first season under conditions of intermittent soil-moisture deficiency were significantly shorter than joints formed at the same time under conditions of adequate soil moisture. Here too the difference tended to disappear as the crop aged. The average lengths of joints formed on the two extreme treatments during the second season showed no significant difference.

The Significance of the Amounts of Water Involved:

As has been suggested small differences in moisture content when expressed as percentage on the wet basis become significant when expressed on the dry basis which alone is permissible if comparisons of actual amounts of water are desired.

Thus a decrease of percentage of moisture from 82 per cent to 80 per cent (wet basis) means that each gram of oven-dried tissue has surrendered 0.55 gram of water during this desiccation. What this amounts to in the water economy of the plant depends, of course, upon the amount of such tissue involved. One method of determining the amount would be to oven dry the entire plant. Another and more practical way would be to compute it.

At Waipio in 1930, plants grown in tanks under rigid irrigation control (6) had produced about 40 pounds of millable sticks at an age of 15 months. If it be assumed that this is the weight at sunrise when the moisture percentage is maximum or 82 per cent (wet basis) the amount of moisture in the cane sticks is 0.82×40 or 32.8 pounds. Apparently there are 7.2 pounds of oven-dry material in the cane.

The moisture percentage on the wet basis now falls to 80 per cent. It is not permissible to multiply 40 by 0.80 in this case since the weight of 40 pounds is associated with a moisture percentage of 82 (wet basis), not 80 per cent. We may however resort to our relationship between percentage expression on the two different bases. Table II indicates that at 80 per cent moisture (wet basis) each pound of oven-dry tissue is associated with 4 pounds of water. From our analysis we have 7.2 pounds of oven-dry material, exclusive of the small amount synthesized between the times of sampling. Consequently the number of pounds of water in the cane at the second sampling is $7.2 \times 4 = 28.8$ pounds. Evidently four pounds of water have been lost from the mature cane in the stool between the hours of sampling.

This cannot be considered as insignificant in the plant's water economy since by gravimetric determinations the daily losses of water from the soil-plant system were normally about ten pounds and rarely exceeded 15 pounds. It is to be noted that the procedure used for measuring daily loss at Waipio (6) failed to differentiate between water lost from the soil and water lost from the plant.

Moreover, the analysis given above fails to recognize contributions from sheaths and green tops which contribute to the daily demand in greater measure, pound for pound, than the mature sticks.

Discussion

There is no thought in this argument that soil moisture is unimportant in considerations of the plant's well-being. The thought is that water may be withdrawn from the transpiring surfaces at a rate greater than the rate of supply by the roots even at high soil moisture contents.

Apparently if the soil moisture is readily available, temporary moisture deficiencies within the plant, caused by rapid transpiration during the day, are rectified by additions of moisture by the roots during the night. The plant has been restored to its normal turgor by sunrise and suffers another period of temporary depletion during the next day if environmental factors are sufficiently intense. If, however, soil moisture is depleted and no longer available at an adequate rate the plant would, presumably, enter a period of intense transpiration demand at a re-

duced moisture level. Further desiccation of tissue would result. Recharging of the tissues by slow replacement by the roots at night would be progressively inadequate. Ultimately the plant would die.

There is little evidence that such minor diurnal desiccations as those suggested above entail economic losses of recoverable sugar. In fact cane in high-producing areas in which high temperatures and intense light are common, such as certain sites near Lahaina, Puunene, Ewa and Kekaha undoubtedly suffer diurnal fluctuations of moisture greater than those reported above.

Nor have we been able to curtail seriously the economic production of sugar (7), (12) by impressing reasonable periods of soil moisture deficiency upon plants grown in carefully controlled experiments. In such treatments the moisture content of the plant must have been lowered during the purposely imposed periods of soil moisture deficiency, although we have no experimental data to demonstrate this deficiency.

In these experiments it was assumed that moisture from the soil was "not readily available" when the soil moisture fell below the permanent wilting percentage. The phrase "not readily available" is not to be interpreted too literally. There is of course some continuing supply from the soil, although at a reduced rate after this arbitrary percentage has been passed. Moreover, from a study of the shape of the soil moisture-surface force curve (9) it would appear that the percentage range of slowly available moisture in Hawaiian soils is broader than with soils on the mainland which have been widely studied. As was reported many years ago (8) "In any event there seems to be a critical soil-moisture content with cane, as in other plants, below which plants function differently than when soil-moisture is more abundant. And this critical soil-moisture constant for cane is numerically close to the wilting coefficient for other plants. Apparently, if the term 'wilting coefficient' is to be applied to soils of interest to sugar cane growers, the term must be redefined or used with reservation."

It is to be remembered too that soil samples, taken for irrigation control of sugar cane, are secured by sampling the first two or two and a half feet of the soil profiles. We have no assurance that roots do not exist in sufficient concentration in lower depths to supply partial turgor to the plant for some time after the soil moisture in the sampled horizon has fallen to our arbitrary limit. The fact remains however that the permanent wilting percentage is a soil moisture content of definite physical significance; its physiological significance is more evident with other plants than with sugar cane.

An Application to Irrigation Control

The argument given above is based upon too little experimental evidence to do more than to suggest a general pattern of internal water relations. More evidence is necessary before these preliminary findings can be applied with any confidence to irrigation control.

But if the general pattern is correct certain possibilities present themselves. One of them is to time the irrigations in such a way that the moisture content in the leaf sheaths before sunrise is never permitted to fall below a critical value. What this value is we do not know but we should be able to identify it so that it may be used to indicate the advent of progressive, uneconomic desiccation of the top of the

plant as a result of soil moisture deficiency. The practical difficulty is that an impossibly great number of plants would be destroyed in the process. Perhaps some function of the many suggested measurements of environment can be used after experimental methods determine the relationship between these measurements and internal moisture relationships.

Another possibility involves observations upon the rate of elongation of young leaves in the top. Repeated observations indicate that the cluster of young leaves crowning the growing point continues to grow at a uniform rate long after the conventional dewlap measurement shows definite retardation. It is possible of course that the growth in this succulent tissue is retarded only when permanent damage has been done to the delicate tissue in the apical meristem. But there are about five leaves between this cluster and the leaf associated with the last visible dewlap. Perhaps one of these will give evidence of incipient moisture deficiency within the plant before an economic loss of growing time and sugar formation is experienced.

If moisture content is a function of Brix value over short periods, refractometer readings of critical tissues might give evidence of significant moisture deficiencies within the plant before damage had been done.

It is recognized that these suggestions are only pertinent if the general pattern of the internal moisture history of the cane plant is of the order that has been suggested. This has not, as yet, been adequately demonstrated although much evidence points toward this interpretation.

In view of the many variables involved it would appear that the best criterion for the need of irrigation will be provided by the plant itself. This criterion can only be identified by an exhaustive study of the internal moisture relationships within the plant.

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Potash Requirements For Sugar Cane

By R. J. Borden

The sugar cane plant is a great lover of potash and, if it has the opportunity to do so, will consume large quantities of this mineral nutrient. This fact gives rise to the natural question of whether in order to function efficiently the cane plant needs as much potash as it will take up. And a logical question which then suggests itself is, "Since the cane plant takes out of a soil such a large amount of potash, are we in danger of depleting the available supply of natural soil potash if we do not fully return that which is taken up by the crop?"

The total potash supply as found in Hawaiian soils is not excessively high when compared with many mainland soils. Van Brocklin (7) has summarized the data from many total potash analyses made at the Experiment Station, and these indicate few soils with less than 12,000 pounds of total potash and many above 25,000 pounds per acre-foot. Furthermore much of this potash is unavailable to crops of the immediate future and, since there is always some doubt that our methods of ascertaining available potash for sugar cane actually do measure the amounts available, our interpretations of potash availability and estimates of potash fertilizer needed are somewhat complicated.

The depletion of soil fertility by removing essential growth elements in excess of what are returned by residues, manures, and fertilizers has been the theme of many agricultural sermons. It is of very particular concern to our planters who grow such heavy tonnages of cane on the same land year after year.

Maxwell (4) has reported the following amounts of K_2O removed per acre by two cane varieties:

Variety	Tons/acre millable cane	Dry wgt. (tons/acre) Cane	Leaves	Lbs. K_2O/acre in dry wgt. Cane	Leaves	Total lbs. K_2O/acre removed
Rose Bamboo	89.36	23.82	26.40	258	882	1140
Lahaina	77.20	22.20	26.31	121	807	928

Hence for each ton of millable cane, Rose Bamboo took up from the soil 12.8 pounds of K_2O, 77 per cent of which was in the leaves and only 23 per cent or 2.9 pounds of K_2O in each ton of the stalks, whereas Lahaina, which took up 12.0 pounds K_2O for each ton of millable cane which this variety produced, had 87 per cent of it in the leaves and only 13 per cent or 1.6 pounds per ton in the stalks.

From one of Stewart's reports (6) we have compiled the following figures from weights and potash analyses of mature H 109 cane from 3 sources:

Source	Net cane tons/acre	Tons/acre Tops and trash	Bagasse and mixed juice	Lbs. K_2O/acre Tops and trash	Bagasse and mixed juice	Total lbs. K_2O/acre removed
Ewa 26B	76.2	19.8	103.3	144.9	179.2	324.1
Ewa 20B	117.7	19.2	159.2	153.8	309.9	463.7
Oahu 10A	102.2	22.3	146.7	201.3	208.6	409.9
Average	98.7	20.4	136.4	166.7	232.6	399.2

These potash figures are considerably lower than those reported by Maxwell for the two different cane varieties which he studied. From them we would estimate that this H 109 cane has taken up only 4.1 pounds of K_2O to produce each ton of millable cane, and that 42 per cent of this potash uptake was in the tops and trash and 58 per cent or 2.4 pounds in each ton of the stalks.

From another study, Stewart presents many analyses from different treatments of H 109 cane which was harvested at different ages at Oahu Sugar Company. We have averaged the potash analyses from these treatments to estimate the number of pounds of potash removed for each ton of millable cane that was secured:

AVERAGE POUNDS K_2O PER TON MILLABLE CANE HARVESTED

Source	At 5 mos.	At 8 mos.	At 12 mos.	At 17 mos.	At 24 mos.
In millable cane only..........	6.31	3.37	2.49	2.15	2.16
In entire plant................	21.47	13.65	6.51	5.63	4.08

Ayres (1) summarizes studies made on H 109 cane at Waipio which indicate that in a long growth period of 24 months, and for a final yield of 99 tons of millable cane, the potash found in the total growth of millable and dead cane, dry and green leaves and tops, amounted to 560 pounds or the equivalent of 5.6 pounds for each ton of cane milled, whereas at the age of 12 months when 52 tons of millable cane had been grown, this crop carried a total of 340 pounds of potash, which is equivalent to an uptake of 7.5 pounds of potash for each ton of millable cane cut at this younger age.

Furthermore, Ayres reports (3) that the percentage of potash varies considerably in the dry matter of the stalks and the green and dead leaves. For example, for his H 109 cane harvested at Makiki at the age of 12 months, he finds .55 per cent potash in the dry matter of the stalks as compared with 2.22 per cent and 1.08 per cent in the dry matter of the green and dead leaves respectively.

In another study (2), Ayres found the percentages of K_2O in the dry matter of 5 cane varieties grown in an identical soil medium to be as follows:

	POJ 2878	Badila	H 109	D 1135	Yel. Cal.
% K_2O in stalks............	1.74	1.16	1.06	1.45	1.34
% K_2O in tops	3.19	2.95	2.98	2.81	2.50

Moir (5) reports percentage figures for potash in two cane varieties as follows:

	H 109	D 1135
% K_2O in stalks................................	.30	.53
% K_2O in leaves and tops	3.19	2.08

Calculations made from other data show that 38 per cent of the total potash found in an H 109 cane crop at 12 months was located in the stalks only. The actual quantity of potash found in H 109 stalks at 12 months by Ayres was 45 per cent of the total amount found in both the stalks and leaves.

However, on the basis of results from six studies which Ayres has summarized (1), he estimates that for each ton of millable stalks alone, in a 2-year crop taken to the mill, there is approximately only two pounds of potash. He believes that this represents the net loss of potash from the field soil, since the remainder contained in the trash and tops stays in the field, and is not materially changed when the trash is burned.

First Study with POJ 2878:

Previous investigations of the amounts of potash contained in sugar cane crops have been generally concerned with total potash found in the crops harvested, and the inference drawn has been that the results have indicated the potash requirements. In few, if any, of these studies that have been made to show the amount of potash taken out of the soil by the cane crop, have variables been present or introduced which would enable one to determine whether potash uptake correctly indicates the potash needs for optimum yields. Hence in an effort to learn more about how this potash uptake may be related to the potash requirements of sugar cane we have now completed two skirmish tests which were planned with this objective in mind.

In the first of these we used the cane variety POJ 2878 and, since indications of heavy tasseling appeared in October, we grew the crop for only nine months, under controlled conditions in Mitscherlich pots each filled with 4,500 grams of Manoa soil. The analysis of this soil by R.C.M. gave the following results:

Ammonia nitrogen	= .0005%	Available K_2O	= .0032%
Nitrate nitrogen	= .0004%	Available CaO	= .014%
Available P_2O_5	= .0008%	pH	= 4.7
P_2O_5 fixation	= 90–75–40	(Replaceable K_2O*	= .0106%)

* % Replaceable K_2O = % K_2O by R.C.M. × 3.3.

At the time of potting all pots were given liberal allotments of phosphate and nitrogen fertilizers, and supplementary nitrogen applications were also made later on. Two single-eye cuttings were planted in each pot in January, and the following 9 differential applications of potash were added at this time.

Treatment No.	Amt. of K_2O supplied	Treatment No.	Amt. of K_2O supplied	Treatment No.	Amt. of K_2O supplied
1	None*	4	.750 gm.	7	3.0 gm.
2	None	5	1.5 gm.	8	4.5 gm.
3	.375 gm.	6	2.25 gm.	9	6.0 gm.

* In Treatment No. 1, the soil was diluted with three-fourths silica sand.

The crop started late in January got off to a very slow start, and because of tasseling it was harvested in October. Cane stalk lengths, diameters, weights, and juice samples were secured, as well as composite samples of plant material (except roots). The potash analyses of plant material were all made by our Chemistry Department. The data which have now been summarized in Tables I and II bring out some interesting facts.

Inspection of Table I will reveal that the optimum yield of cane and sugar probably belongs to Treatment No. 7. A study of Table II shows that Treatment No. 7 was supplied with 3.475 grams of available potash, and that 2.932 grams of this were recovered in the total dry weight that was harvested. This is considerably less than the amounts of potash which were taken up by Treatment Nos. 8 and 9, and indicates a luxury uptake from these two treatments since their resultant cane and sugar yields had not followed their greater potash uptake at the time of harvest. Fig. 1 shows these same relationships, and also an indication that

the total dry weight may have responded more directly to the higher amounts of potash supplied than the millable cane and recoverable sugar; this is undoubtedly because of the high ratio of tops to millable cane in a crop that is only nine months old.

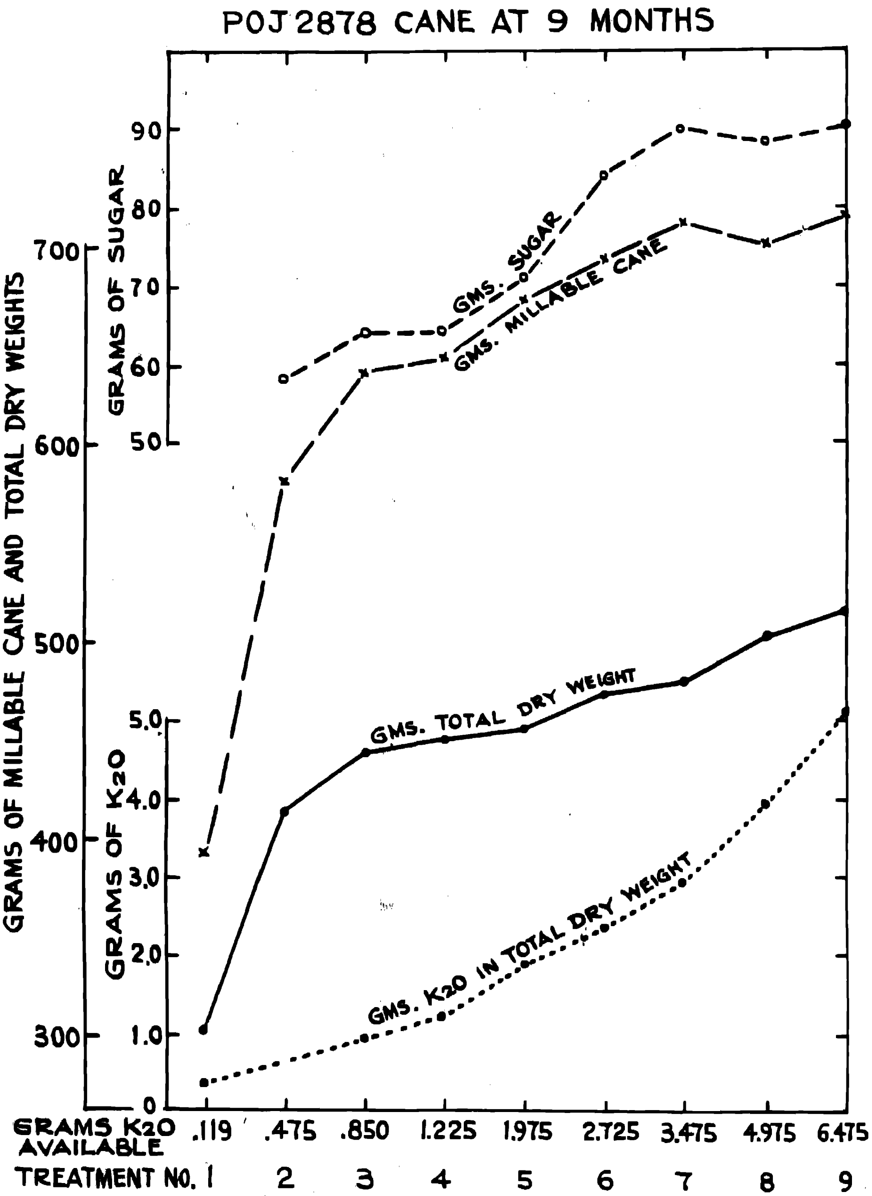

Fig. 1

The data associated with Treatment No. 7 can now furnish us with an idea of the amount of potash that was used for the optimum yield and, if we can interpret them correctly, they should also give us a guide which could be used to design a policy for potash fertilization that would furnish an adequate amount for cane crops and at the same time maintain the soil potash supply.

TABLE I

SUMMARY OF YIELDS VARIETY POJ 2878—AGE 9 MONTHS

No.	Gms. K_2O added	Available[1] potash (gms.)	Stalk length (cm.)	Stalk[4] diameter (cm.)	Cane[2] green wgt. (gms.)	Y%C[3]	Pur.[3]	Sugar (gms.)
1	0	.119	85	1.76	394	*	*	*
2	0	.475	88	2.07	581	9.8	76.6	57
3	.375	.850	87	2.16	638	10.1	76.4	64
4	.750	1.225	86	2.20	643	9.9	77.7	64
5	1.5	1.975	88	2.25	676	10.5	81.7	71
6	2.25	2.725	86	2.24	695	12.1	83.0	84
7	3.0	3.475	87	2.36	713	12.7	86.4	90
8	4.5	4.975	84	2.33	701	12.5	87.4	88
9	6.0	6.475	83	2.40	717	12.5	85.8	90

* Crusher juice too dark to secure readings.
1 Replaceable K_2O plus K_2O added in fertilizer.
2 Average of 4 replicates. Difference needed for significance = 65 grams.
3 From composited crusher juice sample.
4 Stalk diameter taken at uppermost dry-leaf internode.

TABLE II

POTASH UPTAKE BY VARIETY POJ 2878—AGE 9 MONTHS

Treat. No.	Gms. replaceable K_2O in soil	Gms. K_2O added in fert.	Avail.[1] potash (gms.)	Total dry wgt.[2] harv. (gms.)	% K_2O[3] in dry wgt. samples	Grams K_2O in total dry wgt.	% of[4] avail. K_2O recovered	% K_2O in soil after harvest
1	.119	0	.119	302	.123	.371	340	.0008
2	.475	0	.475	416	.165	.687	145	.0008—
3	.475	.375	.850	442	.220	.973	114	.0008—
4	.475	.750	1.225	450	.267	1.202	98	.0008—
5	.475	1.500	1.975	456	.412	1.879	95	.0008—
6	.475	2.250	2.725	473	.494	2.337	86	.0008—
7	.475	3.000	3.475	479	.612	2.932	84	.0008
8	.475	4.500	4.975	501	.782	3.915	79	.0008—
9	.475	6.000	6.475	516	.982	5.064	78	.0008

1 Replaceable K_2O plus K_2O added from fertilizer.
2 Average of 4 replicates. Difference needed for significance = 35 gms.
3 From composited sample of all dried leaves, green leaves, tops and millable cane (no roots).
4 Exclusive of roots.

We find that when the optimum yield of 713 grams of millable cane (and 90 grams of sugar) was produced, 2.932 grams of potash were taken up in the stalks and leaves. This has been estimated* to be equivalent to about 97 pounds of K_2O per acre for a crop nine months old which had a rather slow start and development. The millable cane in this crop at this age is estimated at only about

* $\frac{2.932 \text{ gms.}}{2 \text{ stalks}}$ = 1.466 grams per stalk × 30,000 stalks per acre.

13 T.C.A.*; hence for each ton of millable cane that was produced at nine months, there was a potash requirement of 7½ pounds per ton; this figure is similar to that which Ayres found was taken up in growing a ton of H 109 millable cane to the age of 12 months, i.e., 7.5 pounds.

According to our analysis of this soil, we would expect that an acre to a depth of only 6 inches would furnish 135 pounds of available potash if the cane roots were able to get it all out. In spite of the fact that the cane roots very completely permeated the soil mass in the small pots in which this cane was grown, they were apparently not able to get enough of this potash in nine months, for the optimum yield was not obtained until more potash (3.0 grams) was added from the fertilizer. In fact it would appear that the plants in Treatments Nos. 7, 8, and 9 got very little of this soil supply of K_2O which we have called "available," for the total recovery in the leaves and stalks was slightly less than the actual amounts supplied by the potash fertilizer alone. On the other hand, however, where no or only a very inadequate amount of potash fertilizer was added, we have an indication that considerably more potash was recovered in the plant material harvested than we had estimated as "available K_2O."

Treatment No. 7 which produced 479 grams of total dry weight took up 2.932 grams of potash. This total dry weight at 9 months of age consisted of 60 per cent trash and tops and 40 per cent millable stalks. The stalks had a moisture content of 273 per cent (dry-weight basis)—thus an equivalent green weight of 713 grams. Separate determinations of potash in these two components of the cane sample were not made, hence we must estimate them from other information that has been collected.

A study of Moir's data (5) shows that for H 109 cane the total dry weight consisted of 64 per cent tops and trash and 36 per cent stalks at the age of 8 months, and that this ratio had changed to 34 per cent tops and trash and 66 per cent cane stalks at 12 months. At the 8-month harvest only 25 per cent of the total potash was found in the stalks, whereas at 12 months this figure had become 38 per cent.

Assuming that the trash and tops are to be left in the field and will release their potash for the subsequent crop, our obligation to nature becomes one of returning that which is taken out of the field in the stalks. We might estimate this to be about 30 per cent of the total uptake by cane which is cut at 9 months. Hence 30 per cent of 2.932 grams or only .88 grams would need to be supplied for each 713 grams of these stalks which were milled; this would be equivalent to 2.5 pounds of K_2O per ton of young POJ 2878 stalks taken to the mill. Considerably more than this amount would be needed if much of the trash and tops are hauled away with the stalks.

For cane older than 9 months, we might postulate that the K_2O requirement per ton of millable stalks will be less than for young cane. Ayres' figures have indicated that the potash uptake by 24-month H 109 cane indicated a K_2O requirement that was about one third less for each ton of millable cane than for a 12-month crop (5.6 pounds vs. 7.5 pounds). Moir's data show that whereas 24 tons of cane stalks (only) cut at 8 months carried 80 pounds of K_2O or 3.3

* $\frac{\text{713 gms.}}{\text{2 stalks}}$ = 357 grams per stalk × 30,000 stalks per acre.

pounds of K_2O per ton, 50 tons at 12 months carried 125 pounds or 2.5 pounds of K_2O per ton, and 106 tons of millable stalks harvested at 24 months contained 244 pounds or 2.3 pounds of K_2O per ton. Since a 2-year crop at harvest does not consist entirely of stalks that are *all* 2 years old, but may contain many that are 1 year old or less, perhaps our estimate for potash to be supplied from fertilizer should be based on the ratio of the old-to-the-young stalks harvested. For instance, 60 per cent of the POJ 2878 stalks in a 22-month old 70-ton crop might be of first-season origin, and 40 per cent be less than 12 months old. Our reasoning then would be something like this: The 40 per cent of this 70-ton crop or 28 tons of young stalks would take away potash at the rate of 2.5 pounds per ton—i.e., 70 pounds, whereas the potash removed in the 60 per cent or 42 tons would be at a somewhat lower amount per ton—perhaps at 1.7 pounds per ton or 71 pounds. Thus a total of 141 pounds of K_2O should balance the potash losses as far as such a crop is concerned, and maintain an adequate supply for the next crop—provided none of it is lost.

Discussion:

The very immature age (9 months) at which this POJ 2878 cane was harvested must be remembered in connection with the indication that 2.5 pounds of K_2O should be sufficient to replace the potash taken away from the field in each ton of millable cane stalks only; for older cane we are quite confident that this figure will be somewhat less.

Apparently the results we have secured also indicate that there will be a somewhat greater uptake, for each ton of millable cane harvested, by short than by long crops; this will need consideration in planning amounts of potash to be used on short crops.

In the short 9-month growth period from those treatments which received the heavier application of potash fertilizer, we did not succeed in recovering all of the potash which we had estimated to be available—or even all that which had been applied in the fertilizer. Moreover we did not identify this "lost" potash in the soil after harvest, although it is quite likely that some would have been found in the roots and stubble if these had been weighed and analyzed. Since our technique precluded any actual losses of potash, we shall have to assume that some of the applied potash was changed over and existed in the soil in some form other than that which our chemical analysis identified as available potash. Support to such an assumption is offered by the fact that in Treatments 1, 2, and 3 we note an actual recovery of more K_2O than had been identified as being available when the crop was planted. Apparently therefore, when cane is grown on an available-potash-deficient soil and inadequately fertilized with potash, it has the power of drawing quite heavily not only on the replaceable but also on some form of non-replaceable potash in our soils. And on these same soils, if the applications of soluble potash fertilizer have been in excess of that which the plant has had time to absorb, such potash may become a part of the replaceable and also of this non-replaceable form which is apparently available for sugar cane.

Second Study with H 109 and 31–1389 Canes:

In our second study (Project A–105—94.1) which sought to determine the

amount of potash absorbed by the cane plant per unit of (a) dry matter, and (b) millable cane, and to estimate the amount that leaves the field and that which is left, we used two different cane varieties—H 109 and 31–1389—and grew the crop for a full 12-month period in Mitscherlich pots filled with 4,500 grams of Manoa soil. This particular soil had the following analysis by R.C.M. at the time of planting:

Ammonia nitrogen	= .0008%	Available K_2O	= .0028%
Nitrate nitrogen	= nil	pH	= 4.6
Available P_2O_5	= .0006%	(Replaceable K_2O	= .0092%)

Ample amounts of nitrogen and phosphate were supplied and all conditions except the potash fertilization were made uniform. Two single-eye cuttings were planted in each container in November, after the following 8 differential amounts of potash had been mixed into the soil:

Treatment No.	Amount of K_2O supplied	Treatment No.	Amount of K_2O supplied
1	None	5	4.5 gms.
2	.75 gm.	6	6.0 "
3	1.5 gms.	7	7.5 "
4	3.0 "	8	9.0 "

The crop was harvested at the age of one year, being segregated so that weights and analyses would be available from (a) trash* and tops, (b) millable cane† (bagasse and crusher juice), and (c) roots. Thus we have a much more complete story than we had from our first study. The complete data are given in Tables III to VIII inclusive, and in Figs. 2 and 3 some of these data are shown graphically.

TABLE III

SUMMARY OF YIELDS

VARIETY H 109—12 MONTHS OF AGE

(Averages of 3 Pots)

Treatment No.	Gms. K_2O added	Stalk diameter (inches)	Cane (lbs.)	Brix	Purity	Y%C	Sugar (lbs.)
1	0	1.02	3.55	14.4	79.6	8.01	.28
2	.75	1.05	3.93	15.5	81.9	9.07	.36
3	1.5	1.08	4.20	15.3	80.6	8.72	.37
4	3.0	1.20	4.68	16.8	85.8	10.70	.50
5	4.5	1.16	4.88	16.4	84.9	10.25	.50
6	6.0	1.27	4.65	16.5	86.7	10.65	.49
7	7.5	1.18	4.80	16.9	85.2	10.54	.50
8	9.0	1.18	4.38	17.3	88.6	11.53	.54
Minimum difference required for significance		.10	.65	1.1	3.1	1.59	.11

* Including that which accumulated throughout the entire growing period.

† All stalks were topped at their growing point.

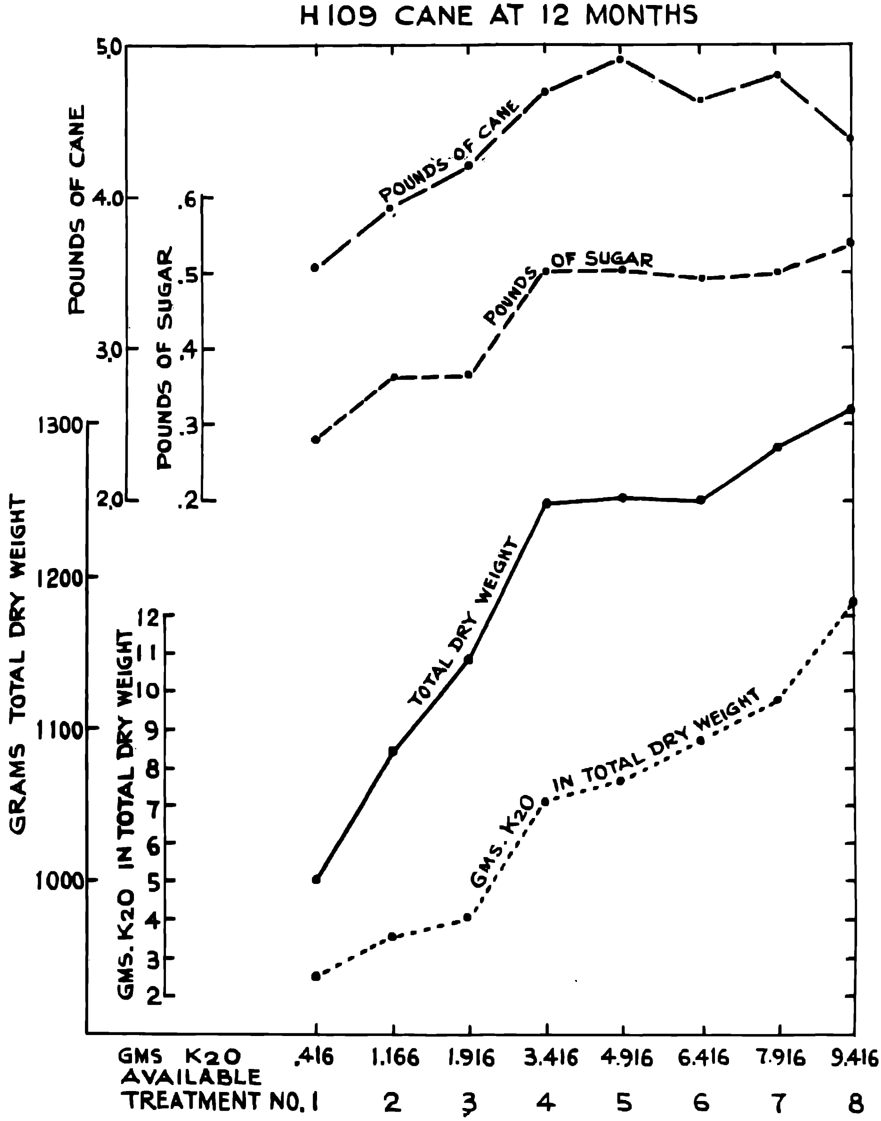
H 109 CANE AT 12 MONTHS
POUNDS OF CANE
POUNDS OF SUGAR
GRAMS TOTAL DRY WEIGHT
GMS. K2O IN TOTAL DRY WEIGHT
TOTAL DRY WEIGHT
GMS. K2O IN TOTAL DRY WEIGHT
5.0
4.0
3.0
2.0
.6
.5
.4
.3
.2
1300
1200
1100
1000
12
11
10
9
8
7
6
5
4
3
2
GMS K2O AVAILABLE .416 1.166 1.916 3.416 4.916 6.416 7.916 9.416
TREATMENT NO. 1 2 3 4 5 6 7 8

Fig. 2

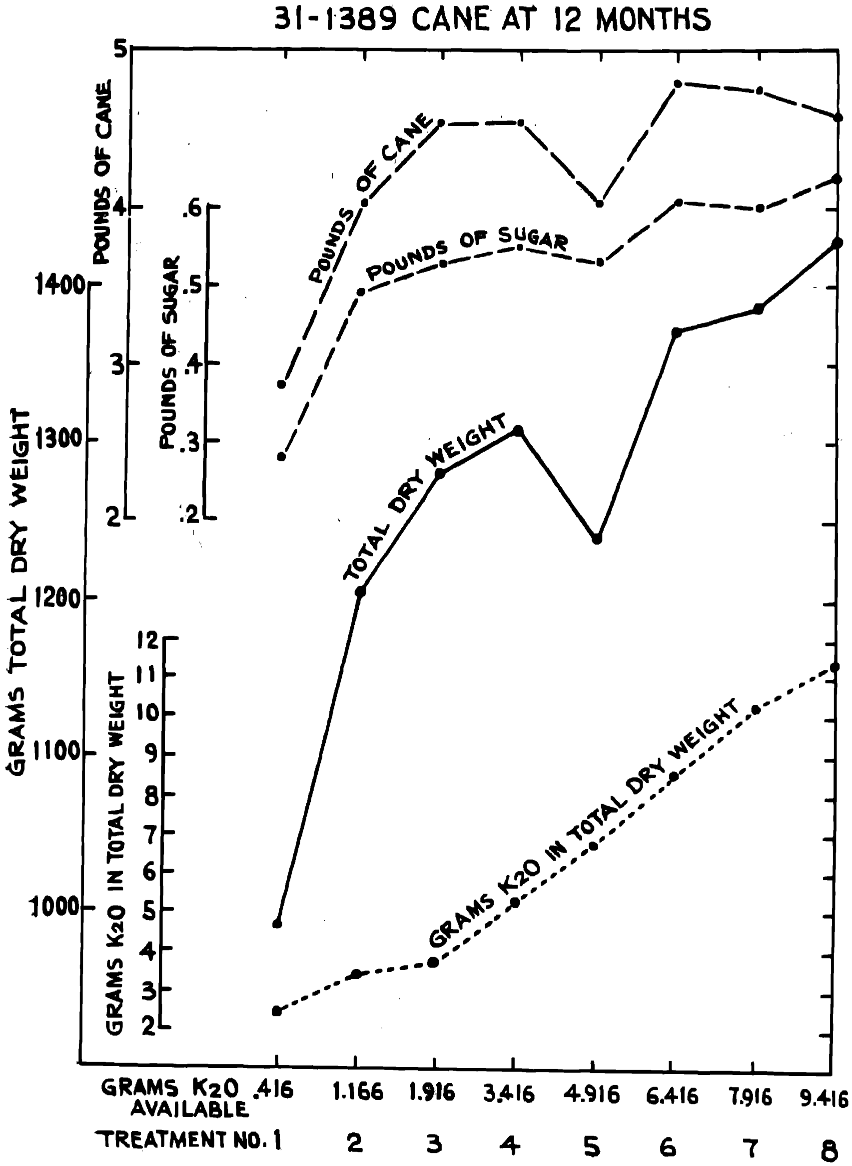
31-1389 CANE AT 12 MONTHS
POUNDS OF CANE
POUNDS OF SUGAR
TOTAL DRY WEIGHT
GRAMS K2O IN TOTAL DRY WEIGHT
GRAMS TOTAL DRY WEIGHT
5
4
3
2
.6
.5
.4
.3
.2
1400
1300
1200
1100
1000
12
11
10
9
8
7
6
5
4
3
2
GRAMS K2O AVAILABLE .416 1.166 1.916 3.416 4.916 6.416 7.916 9.416
TREATMENT NO. 1 2 3 4 5 6 7 8

Fig. 3

TABLE IV

POTASH RECOVERED ON VARIETY H 109 AT 12 MONTHS

Treat. No.	Gms. replaceable[1] K_2O in soil	Gms. K_2O added in fert.	Avail.[2] potash (gms.)	Total gms. dry wgt.[3] (See Table V for detail)	Grams K_2O in total dry wgt.	Percentage of avail.[1] K_2O recovered	% K_2O in soil after harvest
1	.416	0	.416	1000	2.516	605	.0021
2	.416	.75	1.166	1083	3.559	305	.0022
3	.416	1.5	1.916	1141	4.010	209	.0022
4	.416	3.0	3.416	1246	7.103	208	.0022
5	.416	4.5	4.916	1251	7.633	155	.0024
6	.416	6.0	6.416	1250	8.788	137	.0027
7	.416	7.5	7.916	1282	9.692	123	.0027
8	.416	9.0	9.416	1310	12.380	131	.0027

1 R.C.M. K_2O in soil $\times$ 3.3.

2 Replaceable K_2O plus K_2O added from fertilizer.

3 Dry weight of trash and tops, bagasse, roots, and solids in juice.

TABLE V

DETAILS OF DRY WEIGHTS AND K_2O RECOVERED IN VARIETY H 109

Treatment No.	Bagasse: Gms. dry wgt.	Bagasse: % K_2O	Bagasse: Gms. K_2O	Crusher juice: Gms. solids in juice	Crusher juice: Gms. juice	Crusher juice: % K_2O in juice	Crusher juice: Gms. K_2O
1	287	.120	.344	107	745	.020	.149
2	311	.122	.379	130	844	.020	.172
3	343	.148	.508	134	876	.020	.175
4	379	.146	.553	161	958	.020	.192
5	393	.171	.672	166	1011	.020	.202
6	381	.212	.808	161	975	.023	.228
7	383	.223	.854	162	966	.027	.260
8	386	.245	.946	140	811	.043	.353
Totals (all Treatments)			5.064				1.731

Treatment No.	Trash and tops: Gms. dry wgt.	Trash and tops: % K_2O	Trash and tops: Gms. K_2O	Roots: Gms. dry wgt.	Roots: % K_2O	Roots: Gms. K_2O
1	451	.390	1.759	155	.170	.264
2	470	.581	2.731	172	.161	.277
3	488	.610	2.977	176	.199	.350
4	517	1.149	5.940	189	.221	.418
5	522	1.234	6.441	170	.187	.318
6	518	1.426	7.387	190	.192	.365
7	543	1.498	8.134	194	.229	.444
8	570	1.860	10.602	214	.224	.479
Totals (all Treatments)			45.971			2.915

Grams K_2O recovered:

(a) From all Treatments: Ratio of $\dfrac{\text{Trash + Tops + Roots}}{\text{Bagasse + Juice}} = \dfrac{48.886}{6.795} = 7.2.$

(b) From Treatment No. 4 only: Ratio of $\dfrac{\text{Trash + Tops + Roots}}{\text{Bagasse + Juice}} = \dfrac{6.354}{.745} = 8.5.$

TABLE VI

SUMMARY OF YIELDS

VARIETY 31–1389 AT 12 MONTHS

(Averages of 3 Pots)

Treatment No.	Gms. K_2O added	Stalk diameter (inches)	Cane (lbs.)	Brix	Purity	Y%C	Sugar (lbs.)
1	0	.92	2.81	16.2	82.3	9.62	.28
2	.75	1.04	4.01	18.9	86.8	12.22	.49
3	1.5	1.07	4.55	18.4	85.3	11.59	.53
4	3.0	1.05	4.56	18.8	86.7	12.13	.55
5	4.5	1.15	4.04	19.2	89.1	12.99	.53
6	6.0	1.14	4.79	19.2	88.5	12.83	.61
7	7.5	1.09	4.75	18.9	88.5	12.63	.60
8	9.0	1.13	4.61	20.1	90.6	13.96	.64
Minimum difference required for significance		.10	.65	1.1	3.1	1.59	.11

TABLE VII

POTASH RECOVERED IN VARIETY 31–1389 AT 12 MONTHS

Treatment No.	Gms. replaceable[1] K_2O in soil	Grams K_2O added in fert.	Avail.[2] K_2O gms.	Total gms. dry wgt.[3] (See Table VIII for detail)	Grams K_2O in total dry wgt.	Percentage of available[1] K_2O recovered	% K_2O in soil after harvest
1	.416	0	.416	991	2.405	578	.0022
2	.416	.75	1.166	1203	3.310	284	.0022
3	.416	1.5	1.916	1279	3.767	197	.0022
4	.416	3.0	3.416	1308	5.267	154	.0025
5	.416	4.5	4.916	1237	6.896	140	.0022
6	.416	6.0	6.416	1373	8.504	133	.0024
7	.416	7.5	7.916	1381	10.279	130	.0024
8	.416	9.0	9.416	1428	11.417	120	.0024

1 R.C.M. K_2O in soil × 3.3.

2 Replaceable K_2O plus K_2O added from fertilizer.

3 Dry weight of trash and tops, bagasse, roots, and solids in juice.

TABLE VIII

DETAILS OF DRY WEIGHT AND K_2O RECOVERED IN VARIETY 31–1389

	Bagasse			Crusher juice			
Treatment No.	Gms. dry wgt.	% K_2O	Gms. K_2O	Gms. solids in juice	Gms. juice	% K_2O in juice	Gms. K_2O
1	236	.113	.267	82	502	.020	.100
2	337	.139	.468	144	763	.020	.152
3	360	.124	.446	173	923	.020	.185
4	362	.131	.474	158	893	.020	.182
5	331	.168	.556	145	754	.030	.226
6	392	.152	.596	176	922	.020	.184
7	382	.224	.856	163	860	.037	.318
8	380	.263	.999	174	872	.050	.436
Totals (all Treatments)..............			4.662				1.783

	Trash and tops			Roots		
Treatment	Gms.	%	Gms.	Gms.	%	Gms.
No.	dry wgt.	K_2O	K_2O	198	.197	.390
1	475	.347	1.648	218	.180	.392
2	504	.456	2.298	198	.192	.380
3	548	.503	2.756	232	.281	.652
4	556	.712	3.959	dry wgt.	K_2O	K_2O
5	549	1.031	5.660	212	.214	.454
6	575	1.251	7.193	230	.231	.531
7	593	1.436	8.515	243	.243	.590
8	613	1.511	9.262	261	.276	.720
Totals (all Treatments)......................			41.291			4.109

Grams K_2O recovered:

(a) From all Treatments: Ratio of $\dfrac{\text{Trash + Tops + Roots}}{\text{Bagasse + Juice}} = \dfrac{45.400}{6.445} = 7.0.$

(b) From Treatment No. 6 only: Ratio of $\dfrac{\text{Trash + Tops + Roots}}{\text{Bagasse + Juice}} = \dfrac{7.724}{.780} = 9.9.$

H 109 Cane:

In Table III we show the effects from different amounts of available potash upon the yields and cane quality that were obtained. It will be noted that Treatment No. 4 has produced a cane and sugar yield that was not significantly improved when larger amounts of potash were available, and we propose to assume that this treatment was the optimum for the variety H 109.

From Table IV it is apparent that increases in the total dry weights and in the amounts of potash recovered in this dry weight have a linear relationship to amounts of potash (original plus added) in the soil in which this cane was grown. After harvest, the amount of available potash that was left in this soil was certainly not greater than was there when the cane was planted. Hence we may assume that not only did this cane during its 12-month growth period take up all of the potash that had been supplied in the fertilizers, but also that every treatment took more out of the natural soil supply than we had estimated was available. Moreover according to the percentages of available K_2O that were recovered in the crop harvested, it would appear that the drain on the soil's original potash supply was considerably greater when potash fertilization was either omitted entirely or supplied in the smaller amounts.

A study of the optimum treatment, No. 4, shows that the crop started off with a supply of 3.416 grams of available potash, and that during the subsequent 12 months it was able to pick up from some form of potash (which also must have become available) in this soil an additional 3.687 grams, for at harvest we were able to find a total of 7.103 grams in the total dry weight that had been produced. Even this total amount found in the cane from Treatment No. 4 was less than that recovered from Treatments 5, 6, 7 or 8 which we have already noted did not produce significantly more millable cane or sugar than No. 4. So here again we have more evidence of a luxury absorption of potash far in excess of the actual needs for a 12-month crop.

On the assumption that the optimum yield of 4.68 pounds of cane produced by Treatment No. 4 required a total of 7.103 grams of potash, we may estimate* an equivalent need of 235 pounds of K_2O per acre for a 12-month crop of H 109. Since the millable cane yield at this age is estimated at 35 tons†, there has been a potash-plant-food requirement of 6.7 pounds per ton of cane. This figure, however, must not be construed as the potash fertilizer requirement that will be necessary to maintain optimum yields on this soil, for the data in Table V indicate that only a small part of this total potash was found in the bagasse and crusher juice from the millable stalks. Hence under field conditions, the potash in the roots and also that in the trash and tops, provided it remains in the field and is not lost by leaching or tied up in weed growth, will be left for use by the subsequent crop. On this basis our Treatment No. 4 with its .553 + .192 or .745 gram of potash in the bagasse and crusher juice would only remove from the field the equivalent of 25 pounds K_2O per acre or .7 pound K_2O per ton of stalks milled.

31–1389:

Table VI gives the yield data for the variety 31–1389, and we have an indication that the optimum treatment for this variety has been No. 6. Once again luxury consumption of potash is indicated in Table VII, for Treatment Nos. 7 and 8 have taken up considerably more potash than No. 6, without, however, producing significantly greater yields.

As was the case with H 109, the uptake of K_2O and its recovery in the dry matter harvested have exceeded the available supply of this nutrient, and it is again evident that the drain on the natural supply of soil potash (per cent of available K_2O recovered) has been in an inverse relationship to the amounts we have estimated as being available potash. The so-called "available" amounts left in the soil at harvest are slightly less than were there at the start.

In connection with Treatment No. 6 we find that it had an estimated supply of available potash of 6.416 grams at planting, and managed to secure an additional 2.088 grams while growing on this soil, for we recovered a total of 8.504 grams in the total dry matter harvested.

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* $\frac{7.103 \text{ grams}}{2 \text{ stalks}} = 3.55$ grams per stalk × 30,000 stalks per acre.

† $\frac{4.68 \text{ lbs.}}{2 \text{ stalks}} = 2.34$ lbs. per stalk × 30,000 stalks per acre.

These 8.504 grams of potash which were taken up by the optimum treatment for 31–1389 are probably equivalent to 280 pounds* per acre for a 12-month crop. Since its millable cane yield was equivalent to 36 tons† per acre, the potash requirement for this variety has been 7.8 pounds per ton, which is a somewhat higher requirement than we found for H 109 and bears out a general belief that this variety needs more potash than H 109.

As was the previous case however, this figure of 7.8 pounds of K_2O for a ton of 31–1389 millable cane does not necessarily mean that this amount is what must be supplied from fertilizer, for the data in Table VIII show that most of this potash will stay in the field if only the stalks are taken out. Thus in Treatment No. 6, only .596 + .184 or .780 gram of potash was contained in the bagasse and crusher juice, and this would be the equivalent of only 26 pounds of K_2O per acre—which amounts to the same figure of .7 pound of K_2O for each ton of stalks milled that we found for the variety H 109.

Discussion:

The data concerned with H 109 and 31–1389 are difficult to compare with that from POJ 2878 in the former study because of differences in their ages and growing seasons, and because we did not actually segregate for separate analyses the POJ 2878 tops and trash from the stalks. Thus it is somewhat futile to make many comparisons between the two studies.

It is not at all unlikely that the low figure of .7 pound K_2O, that went from the field with each ton of either 31–1389 or H 109 stalks, explains why we have been able to grow and take off large cane crops year after year by supplying from fertilizers only a small part of the total potash that is taken up from the soil by such crops.

It must be remembered that we have secured our data from carefully controlled pot studies in which there were no losses of potash (a) through leaching from the soil or the dry leaves, or (b) by weed uptake. Thus we were able to secure nearer 100 per cent efficiency from the potash fertilizer which we used than will be possible in a general field practice. Furthermore there was no loss of any plant material from our canes during their whole 12-month growing period.

The fact that not more than one seventh of the total potash taken up by 31–1389 and H 109 was found in the stalks after 12 months of growth means that the actual losses of potash in crops taken from our continuously cropped soils are not very large, and that a moderate potash fertilization should maintain a satisfactory status of this plant food, if the cane stalks only are taken from the field. However, with machine harvesting methods that tend to send large amounts of trash out of the field, we will certainly have to increase the potash applications for the low potash soils above those normally used when all trash is left in the field—whether it is burned or unburned.

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* $\frac{\text{8.504 grams}}{\text{2 stalks}}$ = 4.252 grams per stalk × 30,000 stalks per acre.

† $\frac{\text{4.79 lbs.}}{\text{2 stalks}}$ = 2.395 lbs. per stalk × 30,000 stalks per acre.

Summary:

In connection with the formulation of a sound policy of potash fertilization, the results which have been secured from this investigation indicate that we must differentiate between potash uptake by the sugar cane crop and its potash requirement for optimum yields, because a luxury consumption of potash by the cane plant has been clearly shown.

When only the millable cane stalks leave the field, the actual amount of potash that goes with them is not very large. Hence although the total potash taken out of the soil by the growing crop may have been quite large, much of this potash will be left in the trash, tops, and roots in the field.

We have apparently found an indication that the sugar cane plant was able to absorb some potash from a non-exchangeable form that existed in the soil, although the amount taken up was not adequate for optimum yields. There is also an indication that some of the applied soluble potash salts were fixed in the soil in a non-exchangeable form.

Since the ratio of tops and trash to the millable stalks is higher in young than in older cane, and as the per cent K_2O is also higher in the tops and trash than in the stalks, our short crops are going to need potash at a higher rate per ton of millable cane expected than our long crops. However, since these short crops will leave a large amount of their absorbed potash in the tops and trash which are left in the field, a subsequent crop should be able to recover some of this potash.

The fact that we *have* obtained responses in field experiments on low potash soils to applications of 250 pounds K_2O per acre with 2-year old cane crops averaging around 70 tons may mean that we have not secured the full efficiency of these heavier applications. The fact that we *have not* obtained responses to K_2O in some of our field experiments on low potash soils may be because a heavy potash fertilization for a previous crop has furnished a luxury supply which has (a) either become fixed in the soil, (b) been taken up from the soil (and so is not identified in the usual soil analysis), or (c) stored in the leaves and roots and is eventually released therefrom and made available to subsequent crops.

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(4) Maxwell, Walter, 1899. Reports for the year 1899. The Planters' Monthly, 18: 481–511. (Reprinted as Bul. 5, Agr. and Chem. Series, Expt. Stn. H.S.P.A. 1905.)

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
DECEMBER 16, 1940, TO MARCH 14, 1941

Date	Per pound	Per ton	Remarks
Dec. 16, 1940	2.90¢	$58.00	Philippines.
" 19	2.93	58.60	Puerto Ricos.
" 28	2.91	58.20	Philippines, Cubas.
" 30	2.90	58.00	Cubas.
Jan. 4, 1941	2.91	58.20	Philippines.
" 7	2.90	58.00	Philippines.
" 8	2.92	58.40	Philippines, 2.91; Puerto Ricos, 2.93.
" 14	2.925	58.50	Philippines.
" 18	2.92	58.40	Philippines.
" 22	2.93	58.60	Cubas, Philippines.
" 28	2.97	59.40	Philippines.
" 29	2.935	58.70	Cubas, Puerto Ricos, 2.93; Cubas, 2.94.
" 31	2.95	59.00	Philippines.
Feb. 5	2.94	58.80	Cubas, Puerto Ricos, Philippines.
" 6	2.945	58.90	Philippines, 2.94, 2.95.
" 7	2.945	58.90	Philippines, 2.95; Cubas, 2.94.
" 8	2.95	59.00	Cubas.
" 10	2.94	58.80	Puerto Ricos.
" 11	2.955	59.10	Puerto Ricos, 2.94; Philippines, 2.97.
" 13	2.98	59.60	Philippines.
" 17	3.00	60.00	Philippines.
" 18	2.99	59.80	Puerto Ricos, 2.98; Cubas, 3.00
" 19	3.00	60.00	Puerto Ricos.
" 20	3.0267	60.53	Cubas, 3.00; Puerto Ricos, 3.03; Cubas, Puerto Ricos, 3.05.
" 21	3.05	61.00	Puerto Ricos.
" 25	3.11	62.20	Philippines, Puerto Ricos, Cubas, 3.10; Philippines, 3.12.
" 27	3.15	63.00	Puerto Ricos, Cubas.
Mar. 7	3.20	64.00	Puerto Ricos.
" 12	3.265	65.30	Cubas, 3.25; Philippines, 3.28.
" 13	3.28	65.60	Puerto Ricos.
" 14	3.30	66.00	Cubas, Puerto Ricos.

④ THE HAWAIIAN
PLANTERS' RECORD

Vol. XLV THIRD QUARTER 1941 No. 3

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Weed-Control Methods Influence Subsequent Weed Types:

A story of the way in which different weed control practices can influence the subsequent type of weed growth is aptly told in a series of photographs taken at the Wailuku Sugar Company.

Further Studies in Nitrogen Nutrition:

Time-of-Application-of-Nitrogen Test: A series of plots was laid out at Makiki to (1) study the effect of nitrogen fertilization on the growth and yields of the sugar cane plant, (2) study the physico-chemical and biochemical changes within the plant, and (3) derive therefrom information as to the reasons for variation in sucrose content of the plant. In a previous paper a report was made on the effect of nitrogen when applied in one application. In the present paper some of the theories advanced in the first paper are expanded and additional findings indicated as developed by multiple successive applications of nitrogen under growing conditions similar to those reported in the first paper.

Midway Islands:

The establishment of an airport at Midway Islands by the Pan American Airways Company in 1935 has resulted in making this American possession popular with large numbers of people who have since stopped there enroute to or from the Far East. An account is given of the geographical position, geology and modern history of the region, together with a descriptive narrative of the fascinating habits of the many birds that spend part or all of their time on the Islands. The author has studied the strange and interesting habits of the sea birds of Midway almost continuously for 6 years and has given an accurate picture of their various life histories.

Weed-Control Methods Influence Subsequent Weed Types

Through the courtesy of the Wailuku Sugar Company, we are permitted to present some interesting photographs taken by D. S. Judd within the ratoon areas of a field of 32–8560 cane.

The legends below the pictures identify plots which had been given different weed-control practices in the previous or plant crop. These may be briefly enumerated as follows: All plots received one hand hoeing, early. Thereafter, the "A" and the "B" plots were not weeded again, but the "B" plots received extra nitrogen fertilizer to compensate for that which was used up by the weeds. In the "Y" plots, subsequent weed control was by means of four sprayings with a standard herbicide, while at the same time the "X" plots received four hand hoeings.

It will be noted that a very different and distinctive type of weed growth has evolved from the differences in those methods of weed control which were used on the previous crop of cane. The prevailing weed in this current crop, on those areas which were not weeded in the former crop, is the soft, succulent annual type, whereas the tougher, more wiry grasses have persisted where herbicidal sprays or hand weeding had been the previous method of weed control.

(R. J. B.)

Fig.1. In the previous crop of plant cane grown on this area, the weed growth was not controlled. Note the abundance of the quick-maturing "milkweeds" which have survived and now dominate the area of this first ratoon crop of 32–8560 cane.

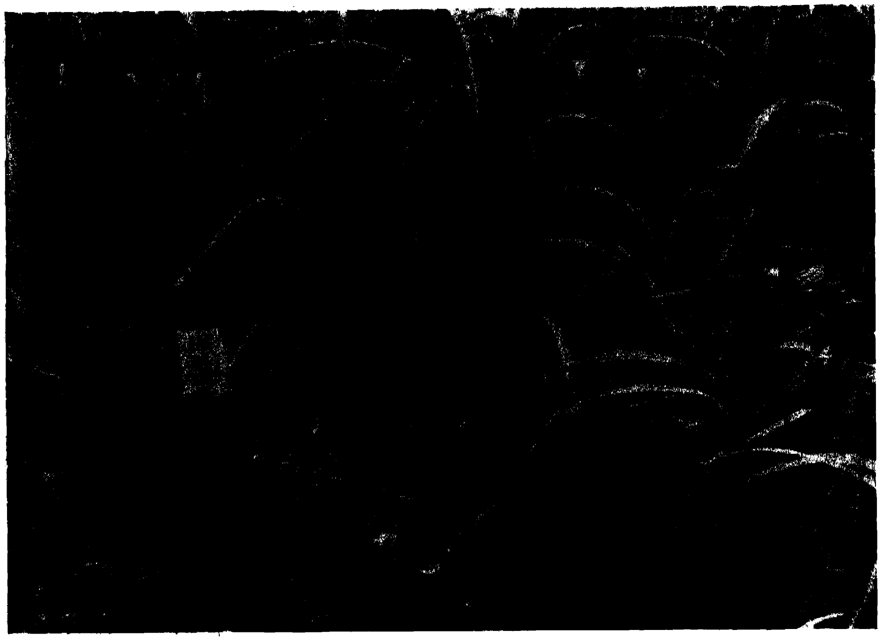


Fig. 2. A practice of no weeding plus extra nitrogen fertilization for the previous cane crop has also left its legacy of the fast-growing, succulent weeds which apparently are holding down the grasses.

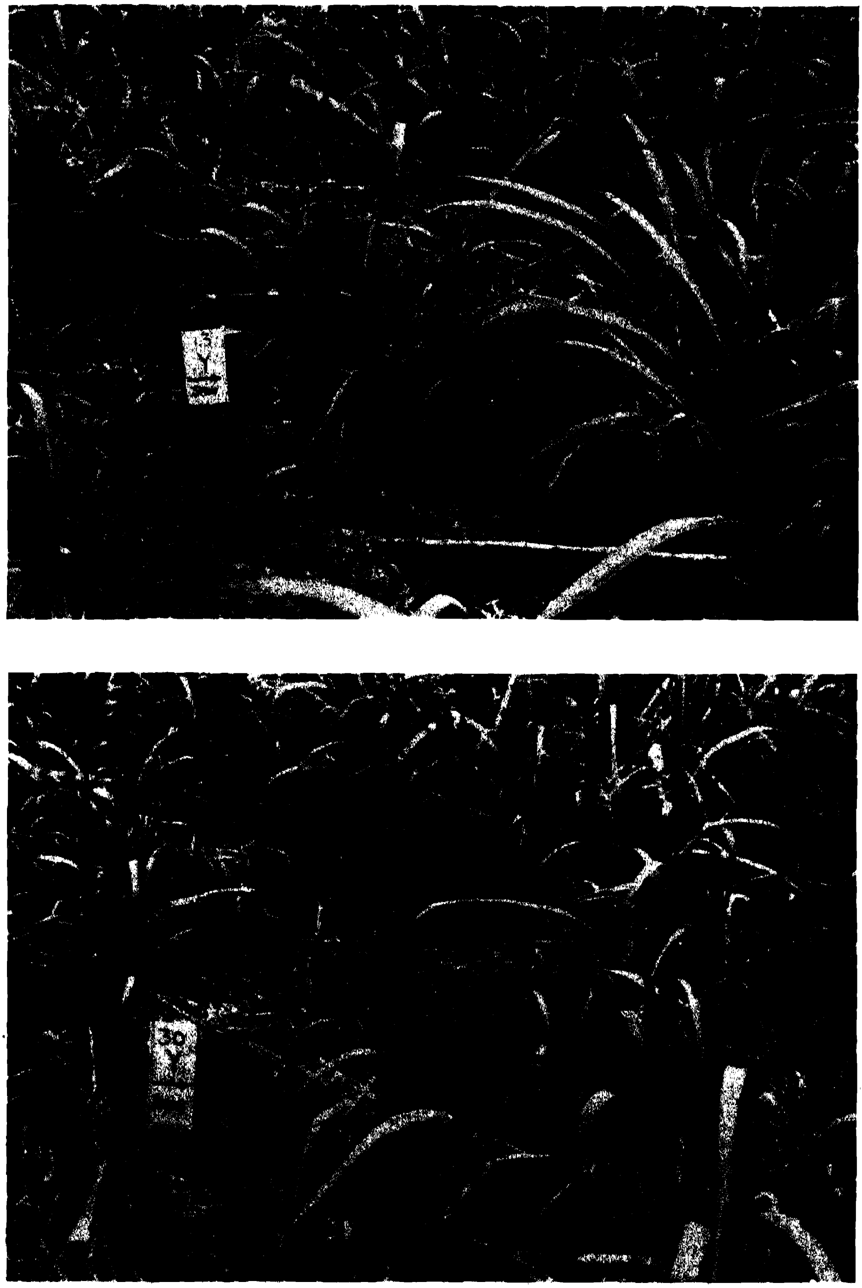


Fig. 3. Where standard herbicides were used for weed control in the previous crop of cane, the succulent easily killed weeds have now disappeared and the tougher, wiry, grassy types have become more firmly established.

Fig. 4. Four hand hoeings to control the weed growth in the previous cane crop apparently conquered the easily killed weed types, but left a heritage of seed of the tougher grasses which are not so easily controlled.

Further Studies in Nitrogen Nutrition

TIME-OF-APPLICATION-OF-NITROGEN TEST

By A. H. CORNELISON AND H. F. COOPER

A discussion of the effect of varying amounts of nitrogen when supplied to sugar cane in a single application at the age of 1½ months was submitted in a previous issue of *The Hawaiian Planters' Record* (Vol. 44: 273–308, 1940), and a description of the plan and objectives of a series of three studies in nitrogen nutrition was given as the introduction to the presentation of the results from the first of these studies—the Amounts-of-Nitrogen Test.

The present paper aims to discuss the results from the second series of plots that was included in this investigation, i.e., the results which were the effect of nitrogen when supplied to sugar cane in multiple applications.

Treatments:

At the age of 1½ months a basic dressing of both superphosphate and muriate of potash, at the rate of 200 pounds per acre of P_2O_5 and of K_2O, was applied to all plots alike. Single plots were then given differential applications as follows:

Identity	Total lbs. N/Acre	Number and time of applications
E	400	In 10 applications of 40 lbs. N each at 2-month intervals.
H	250	In 10 applications of 25 lbs. N each at 2-month intervals.
G	250	In 1 application at 1½ months.
F	250	In 3 applications: 50 lbs. at 1½ months in July; 125 lbs. at 3 months in September; and 75 lbs. at 10 months in March of the second season.

The total amount of nitrogen given to Treatment E was known to be normally excessive at Makiki, but it was applied in this quantity in order to compare the results with those secured from the "D" plots which were discussed in the previous study and which had likewise received 400 pounds of nitrogen in a single application at the age of 1½ months.

Treatment H was supplied with a total amount of nitrogen which was believed to be optimum for Makiki under normal weather conditions. Its use in 10 bimonthly applications of 25 pounds each allowed good comparisons with the "G" and "F" plots, and to a lesser extent with the "C" plot of the former study which had received only 200 pounds of nitrogen at the age of 1½ months.

Treatment G which received 250 pounds of nitrogen per acre in one application at 1½ months of age was designed as the control for the "time-of-application" series of plots. While the behavior of this plot was not exactly the same as that of the "C" plot discussed in the former study, it was not too different to allow a general comparison to be made.

The application of 250 pounds of nitrogen to the "F" plot corresponded to normal plantation practice for cane crops started in May.

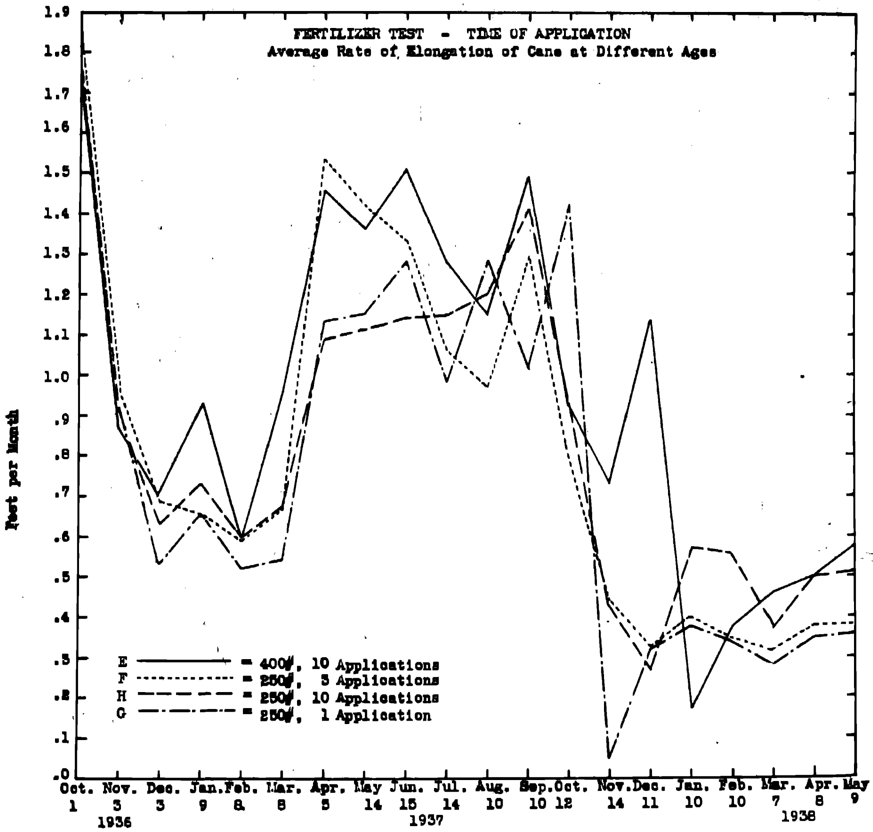

FERTILIZER TEST - TIME OF APPLICATION
Average Rate of Elongation of Cane at Different Ages
Feet per Month
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.0
E = 400#, 10 Applications
F = 250#, 5 Applications
H = 250#, 10 Applications
G = 250#, 1 Application
Oct. 1
Nov. 3
Dec. 3
Jan. 9
Feb. 8
Mar. 8
Apr. 5
May 14
Jun. 15
Jul. 14
Aug. 10
Sep. 10
Oct. 12
Nov. 14
Dec. 11
Jan. 10
Feb. 10
Mar. 7
Apr. 8
May 9
1936
1937
1938

Fig. 1

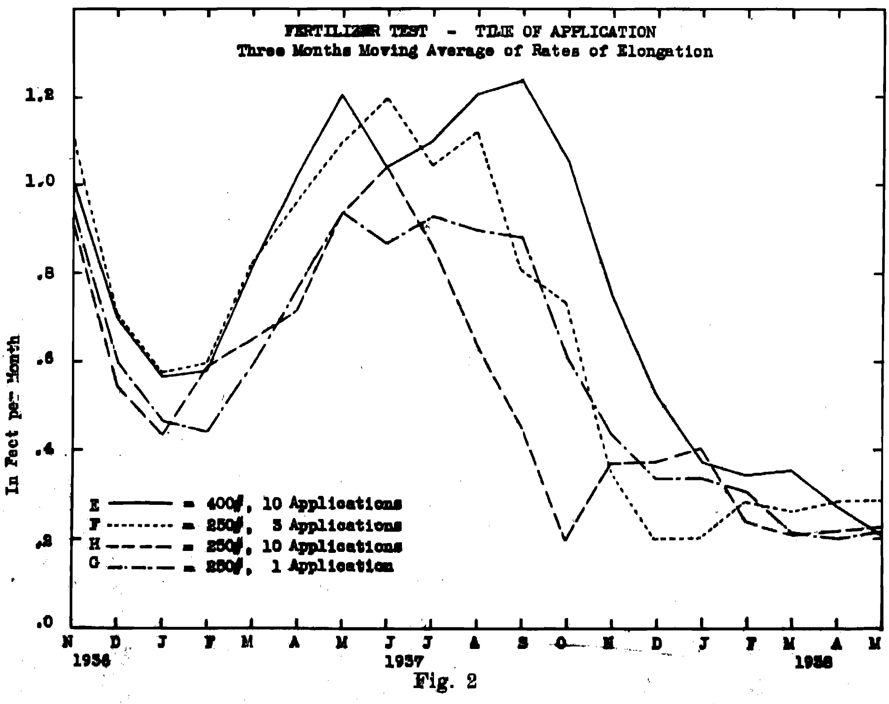

FERTILIZER TEST - TIME OF APPLICATION
Three Months Moving Average of Rates of Elongation
In Feet per Month
1.2
1.0
.8
.6
.4
.2
.0
E = 400#, 10 Applications
F = 250#, 5 Applications
H = 250#, 10 Applications
G = 250#, 1 Application
N D J F M A M J J A S O N D J F M A M
1936
1937
1938

Fig. 2

All nitrogen was applied in the form of sulphate of ammonia.

The same biochemical, physico-chemical and physical determinations were made on cane harvested from this series of plots as in the former series. Harvesting was carried out every two months and irrigation practices corresponded to those of the former block of plots, i.e., sixteen inches of water were applied per month throughout the crop life.

The "time-of-application" treatments were so effective that visual inspection of the field revealed the trends that were later found in the actual analytical data from the plots. As these differences in vegetative behavior were expected, they were followed closely by physical determinations in the field.

Total and Rates of Elongation (Figs. 1, 2, 3):

At one-month intervals growth measurements were made on 25 representative first-order stalks in an inside line of each plot. In general the average length of stick at each measurement was found to be approximately proportional to the total nitrogen which had been applied prior to the measurement.

The seasonal effects, as well as the general relationship of temperature to elongation as previously found in the "amount-of-nitrogen" test, also held in this series of plots.

As shown in Fig. 3 total elongation of the stalks in the various treatments was influenced not only by the amount of nitrogen applied but also by the timing of the application as well as the state of weather at the various seasons which the crop experienced during its life. In Figs. 1 and 2 wherein the rates of elongation are shown, the marked effects of seasonal temperatures are obvious as all treatment curves show decreased rates during the months of November, December, January, February, and March of the first year of growth. In the same months of the second winter (and further prolonged into the month of June) we also find decreased rates of elongation. Study of temperature curves for this second decreased-rate period indicates that not only season but also physiological age were the deterrents to growth therein.

It will be noted in Figs. 1 and 2 that rates of elongation, while reduced absolutely during cool periods, still maintain their relative positions as established by their prior nitrogen fertilization so long as age does not interfere.

The rates of elongation curves of plots "E" and "F" (Fig. 1) for the months of April, May, and June of the first year show also that the presence of recently applied, more adequate available supplies of nitrogen allowed these treatments to respond more rapidly to temperature influences, when these became favorable, than could plots "G" or "H".

The total-length-of-stick data (Fig. 3) indicate that although we can by a single heavy application of nitrogen at an early date ("G") get increased stalk length initially, we can by proper use of seasonal and age influences, and the same total nitrogen application, get greater total elongation of stalk over a two-year period as shown in the curve for "F" plot.

On first glance Fig. 3 would seem to indicate that possibly heavy multiple applications as in "E" would give the greatest cane yields since the stalks were so much longer. Exemplified herein is the inadequacy of total elongation figures when used alone as an index of cane growth. As will be seen later this plot produced actually

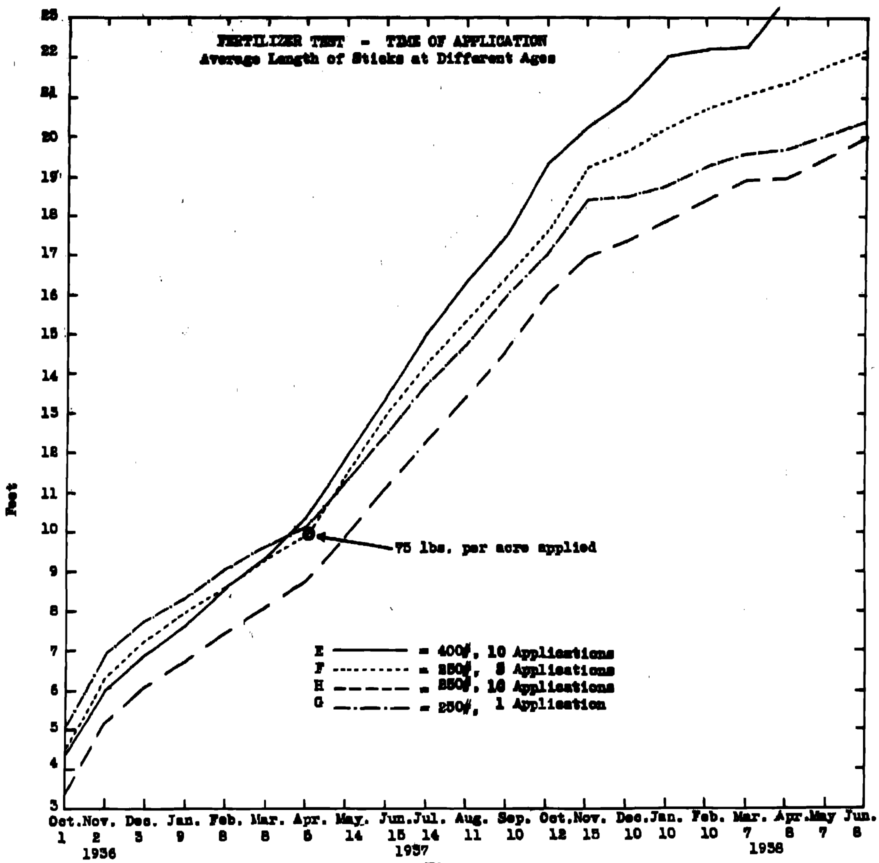


Fig. 3

little or no more millable cane by weight than did the shorter stalks in "F" or "G" plots.

It might be pointed out that by observation in the field, both "F" and "E" plots appeared more etiolated or slenderer and weaker stalked than the other two plots, especially in the second fall and winter. Thus one may infer that the additional stalk length did not represent true increases in growth.

In all three figures (1, 2, and 3) the complete inadequacy of small multiple applications of nitrogen as in "H" plot is apparent. This plot over a 22-month period received, however, the normal optimum Makiki application. Comparison of growths in this treatment with those of the "F" treatment point to the effect of timing on the efficiency of nitrogen applications.

The need for graduated applications of nitrogen as determined by the quantity of cane in the field, which we have deduced from the elongation and other data presented, will be covered in our "Discussion."

Stand of Cane (Figs. 4, 5, 6, 7):

The original stand of cane was again limited to 65 primary stalks per twenty-foot of line, up to and including the fourth month after planting. With this initial

equal stand at the beginning of the crop, whatever differences were found at each harvest after the fourth month were considered to have been due to the nitrogen treatment. Thus when the various age classes of cane were studied at each harvest, the effects of nitrogen on tillering, mortality, lodging, tasselling, elongation, and lala-ing were noted.

Much of the effect of nitrogen on juice quality at the final harvest was shown in our previous study to depend upon the prior vegetative behavior; this in turn is greatly influenced by the timing of the nitrogen application.

In the multiple-application plots secondary growth was high (Fig. 4). Parallel with this heavier tillering condition, the mortality of sticks from the original stand of "primaries" was less at harvest in these plots than where the single application was given (Fig. 5).

The number of dead sticks in treatment "F"—the plantation practice plot—was the lowest of all the treatments, and the millable, living population for all orders of stalks was the largest. A study of the data in Fig. 5 shows that in this "F" plot, after 16 months of age, the secondary growth was largely grouped into the millable-cane class, and that the competitive relations of the primaries and the secondaries were not conducive to death in either group. Due to this competition, however, there was induced a condition bordering on etiolation; more will be said of this condition later under "Yield of Cane."

As was noted in our former study, we again found the same causes of early mortality, i.e., a higher death rate when the nitrogen was applied in a single early application. No evidence was found that disease, insects, or mechanical injuries were responsible for this dead cane.

Composition of Crop—Suckers or Tillers (Figs. 4, 5, 6, 7):

The percentage of total millable cane composed of first-order sticks in the multiple-application plots is seriously affected about the fourteenth month by the inclusion of a considerable number of suckers or secondaries which had started in the previous late fall or early spring. The crop is thus made up of about 65 per cent first-order stalks and the remainder of more or less immature second-order stalks; this same condition was found also in a report made in 1936* in which multiple applications of nitrogen were supplied.

In the former study the single-application series of plots gave higher percentages of first-order stalks in the crop at all ages. This substantiates the general experience that tillering is increased not only by increased amounts of nitrogen, but also by continued nitrogen applications or availability. In addition to these sticks of secondary origin which finally become millable, a large number of suckers were started in the summer of the second year which were never to become millable and thus represented economic losses. These late suckers were more numerous and heavier in the two 10-application treatments ("E" and "H").

Although these sticks were of such a size as to force their inclusion in the millable-cane classification, their juices were naturally poorer than those of the primary or early started secondary sticks. Thus not only did a too long spread of

* Das, U. K., and Cornelison, A. H., 1936. The effect of nitrogen on cane yield and juice quality. The Hawaiian Planters' Record, 40: 35–56.

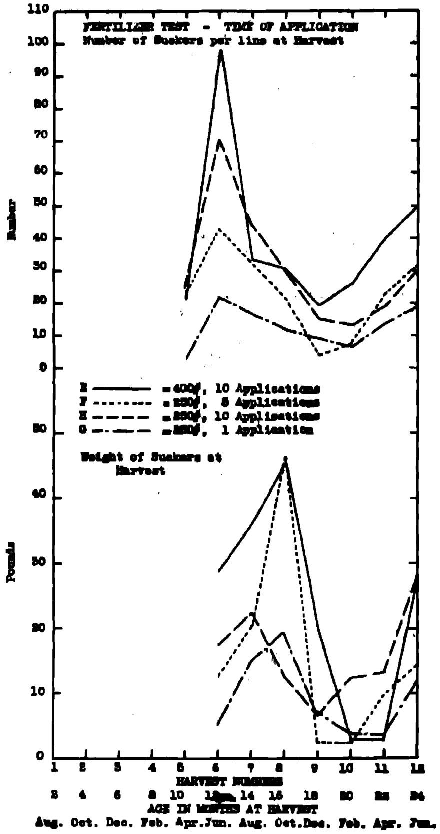


Fig. 4

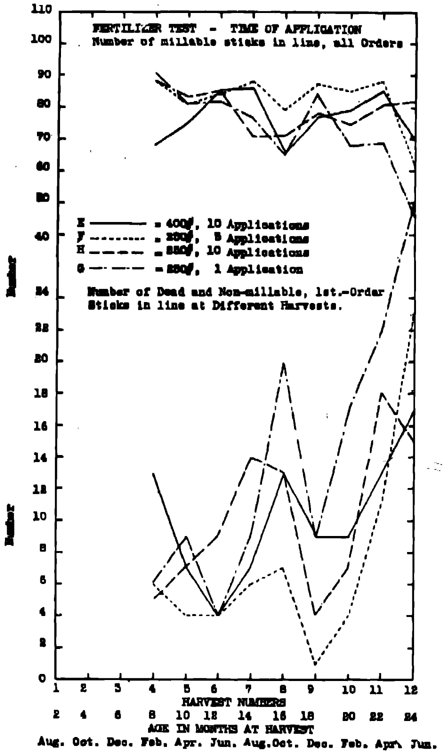


Fig. 5

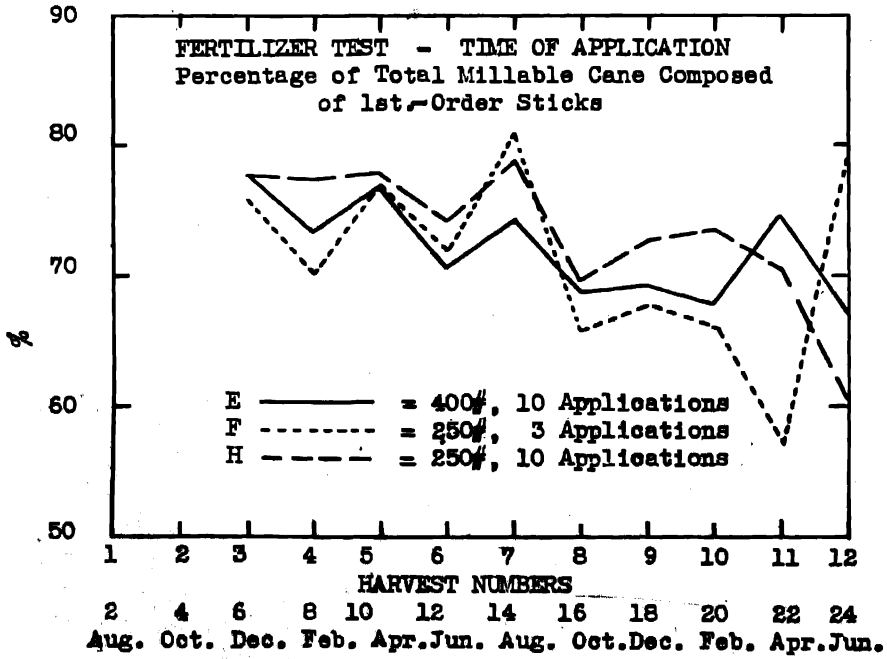


Fig. 6

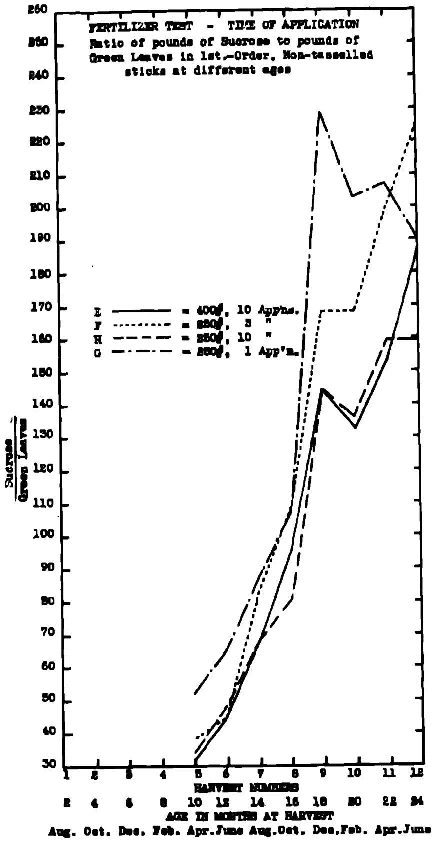


Fig. 7

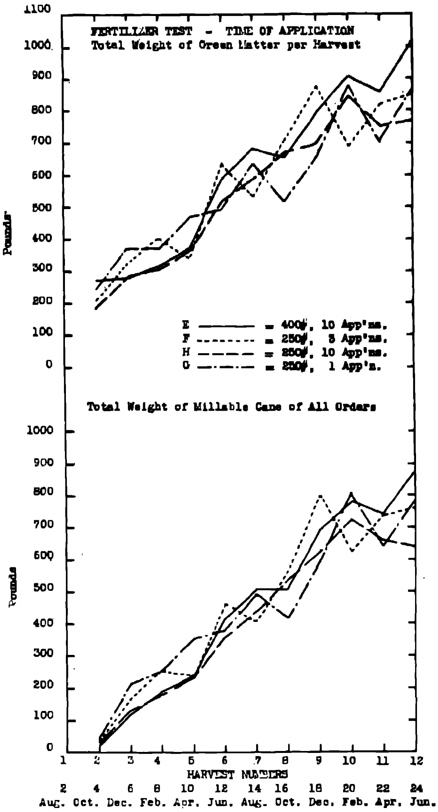


Fig. 8

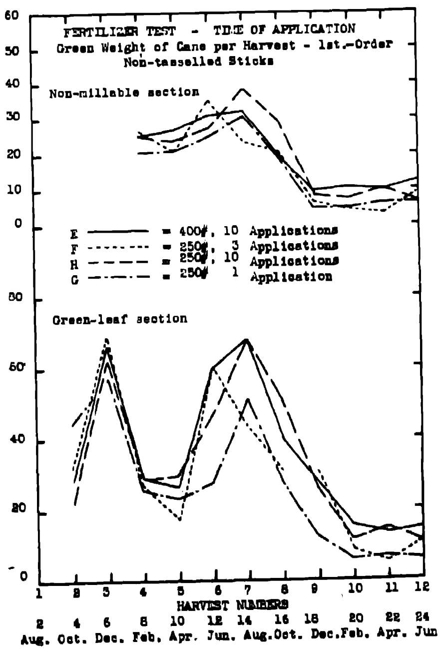


Fig. 9

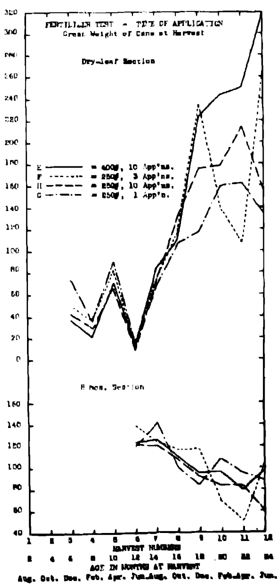


Fig. 10

the nitrogen applications produce juice of poorer quality, but it produced much non-millable tiller growth which was uneconomical.

The cane which received its nitrogen in many applications produced a higher amount of green top and leaf material which carries no recoverable sugar. This will be a factor where the present methods of mechanical harvesting result in this material going to the mill.

Yield of Cane (Figs. 8, 9, 10, 11, 12):

In harvesting, the cane in these plots was divided into season and age-of-cane groups in the same manner as the plots in the former "amounts-of-nitrogen" series.

The same three definite slopes of curves in the ratios of stick formed to weight of associated top were found as in the "amounts-of-nitrogen" test (Fig. 12). Closer examination of Fig. 12 shows that there is a definite proportional increase in non-millable top matter in the multiple-application plots over the single applications. Thus these plots appear to produce more leaf weight in proportion to the weight of stick formed at any age, as well as poorer sucrose concentration (in expressed juice), than does the single application.

The cane yields of first-order sticks from the season and age-of-cane sections of stalk (Figs. 9, 10, 11) show approximately the differences in weights that the growth measurement data led us to believe existed. However, when we consider total millable cane weights from stalks of all orders, we find rather small differences between the treatments except in the case of "H" plot in which growth was depressed.

The more we study the data for these age sections in the first-order sticks the more the conclusion is forced home to us that the timing of nitrogen applications allows us to choose the period of life in which we want our crop to make its maximum growth, controlled of course by season, age, and the temperature limitations imposed by location.

In the later part of the crop life, especially in the dry-leaf sections, we find that the weights of millable cane made in our multiple-application treatments are greater than those from the single-application treatments. However, if we go back to the early period of growth made in the "four-month section," we find that the "G" plot which had a single application is far in the lead in weight of cane formed—sufficiently far ahead to largely balance the continuous gains made later on by the multiple-application plots, at least up to about the sixteenth month after which the mortality, tasselling, and derangements in nitrogen metabolism exert their influences.

Juice Quality (Fig. 13):

As was the case in the "amounts-of-nitrogen" part of this experiment, the presence of supplies of available or applied nitrogen in the soil soon resulted in reduced purities of the cane juices. In the "H" and "E" plots, which received their nitrogen in 10 applications, higher water content of tissue and considerably higher quality ratio figures were found.

However, from Fig. 15 wherein are plotted the actual pounds of sugar recovered at each harvest, it is almost impossible to discern any great differences in yield among any of the treatments. Individual variations are greater than treatment effects when total pounds of sucrose are considered.

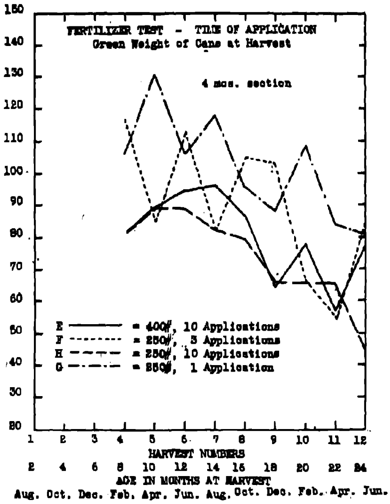


Fig. 11

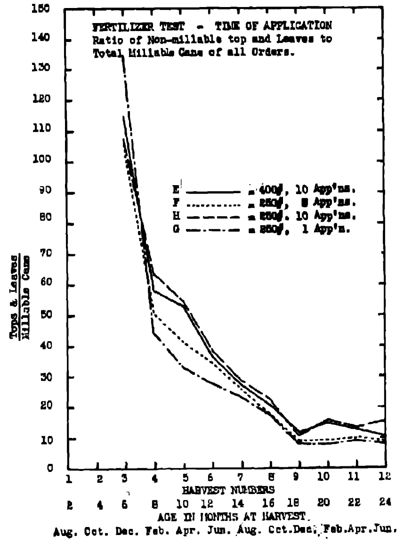


Fig. 12

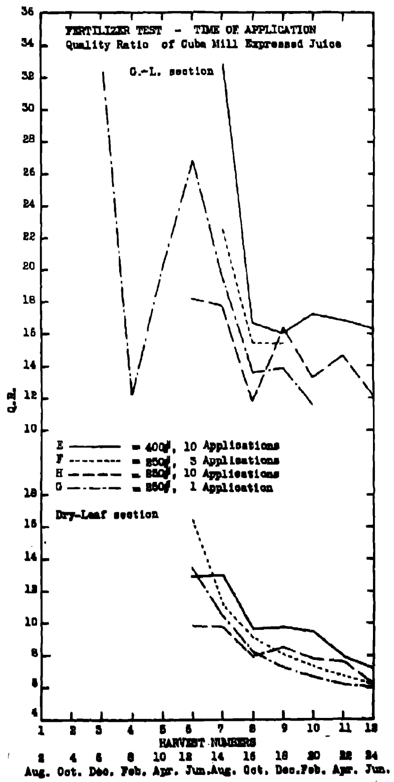


Fig. 13

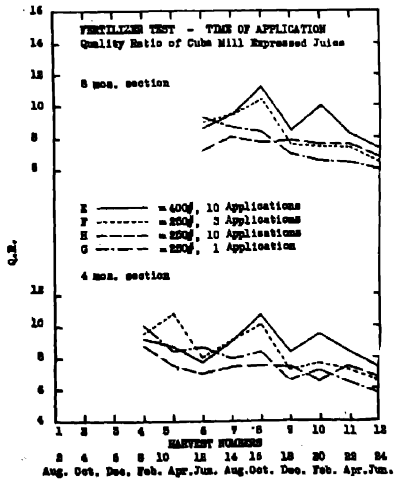


Fig. 14

As we have previously stated, juice quality is related largely to vegetative activity. Thus season, available nitrogen and age will be major factors to watch to improve juice quality. An adequate supply of water is also important, in that lack of it may act as a limiting factor in the responses to the stimuli of any of the other growth factors. However, we do not feel, from information obtained from our irrigation test (to be reported later), that large amounts of available water in the soil will *per se* induce very poor juice quality *without the activating influence of one or all of the other factors.* We found that we could improve juices by the removal of water some months prior to harvest (by drying off) only *when the cane is old enough and the season of the year is favorable for the retardation of growth and respiration rates.* This finding needs further study and a repetition of the test.

Water Content (Fig. 16):

The presence of a continuous supply of available nitrogen large enough to promote normal growth and, as in this case, multiple applications, causes sugar cane to maintain higher hydration levels in all anatomical parts later in life than the plant would maintain under a single nitrogen application. The higher hydration status so induced shows less age variations (in the multiple-application plots) than in the single-application plots.

This increase in water content is accompanied by changes in glucose and sucrose percentages. The plant tissues under conditions of higher hydration are also softer and more succulent.

The increased water content of tissues which received the higher nitrogen, as well as those exposed to smaller but prolonged nitrogen applications, appears to be associated not only with the activity of the living cell content but also with the condition of the non-living cell wall materials themselves. We found that dead, oven-dried material re-absorbed moisture from the air of the laboratory roughly in the relative proportions that were held by the tissues during life.

The so-called celluloses, hemicelluloses and other organic materials, therefore, must be considered as one part of the cause of the higher hydration values in high or prolonged nitrogen treatments. These determinations were not made, due to the large scale of these tests and the rather arbitrary chemical analysis methods for these materials. From ash analysis data obtained by A. Ayres we can only conjecture that the concentration of calcium, which was heavily increased as a result of increased or prolonged nitrogen applications, was the major inorganic swelling agent conducive to making these cell wall materials more capable of absorption of moisture. Fundamentally, of course, increased activity of nitrogenous protoplasmic materials, under continuous nitrogen availability, was the chief cause of the hydration of tissue, for it is within the protoplasmic complex that the qualitative and quantitative conditioning of the entire group of living and non-living cell constituents is controlled.

The data indicate that the permanent conditioning of the storage cell, in connection with its general sucrose and water-holding capacities, depends on the nitrogen which is available during the periods of formation and maturation of the tissues considered. It is possible, therefore, to influence permanently to a certain degree any set of joints in the stick by nitrogen treatment during the time of the

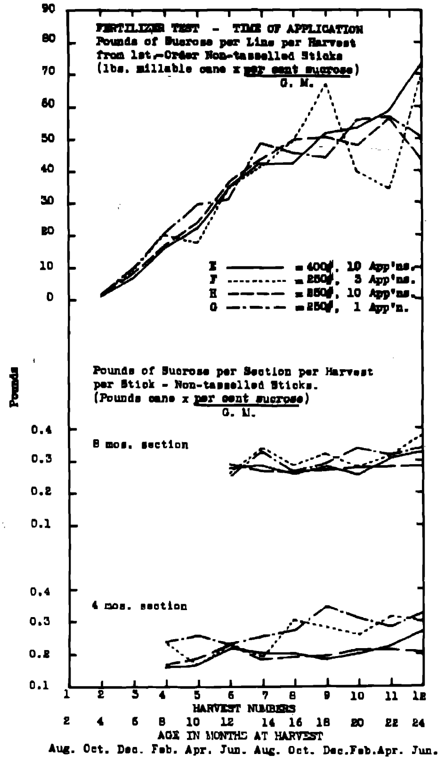


Fig. 15

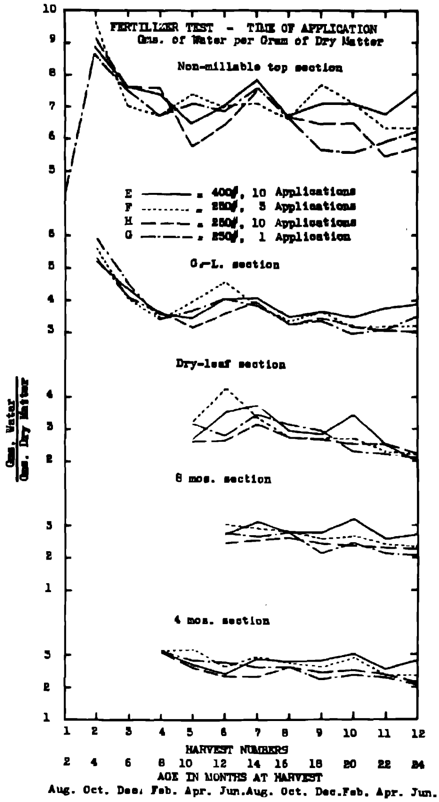


Fig. 16

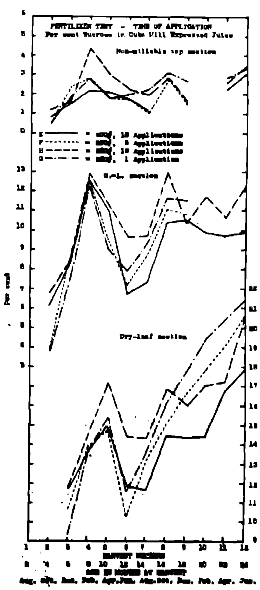


Fig. 17

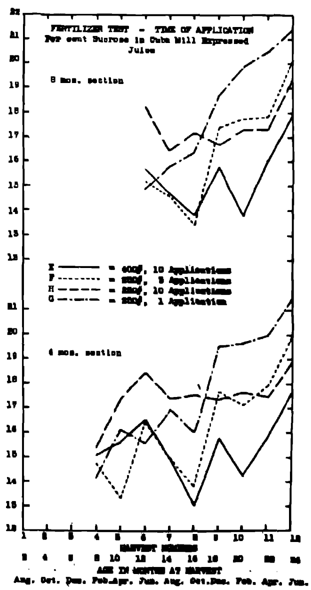


Fig. 18

development of those joints. Those which were formed at an earlier date show temporarily the detrimental effects of subsequent nitrogen treatment but these effects, as far as can be determined, are not permanent.

If we remember that a cane stick is primarily a phytomer and that each joint is a separate plant making up a formal community of plants, it is easier to grasp the conception that each joint or section of joints represents the accumulated effects of all growth factors operative at the time of its formation, plus the general physiological inheritance of the community as a whole. Thus if one were to conduct a post-mortem on a stick of cane joint by joint one could trace, to a certain degree, its prior living conditions so far as water, temperature, energy, or plant nutrients were concerned. Therefore the growth conditions at the time of the formation of a section of stalk are, to a large extent, responsible for the limits of water and sucrose that can be stored in a given joint or section in a stick of cane. *The total cell capacity is established but not the final concentration of the cell contents.*

Sucrose Content (Figs. 18, 19, 20, 21):

The sucrose content of the cane was determined in two ways: (1) by polarization of Cuba mill expressed juice, and (2) by determining the percentage of sucrose in cane tissue on an oven-dry basis. The concentration of sucrose in juice was, as one would expect, lower in the higher nitrogen-treated plots and in those plots receiving continued applications. As long as the nitrogen in the soil was maintained at different levels, effecting thereby differential rates of growth, the levels of water content and sucrose content were directly affected, i.e., an increased growth rate was invariably accompanied by increased hydration and depressed sucrose concentration, while a decreased growth rate was accompanied by the opposite conditions.

When, through nitrogen shortage or seasonal temperatures a hindrance to growth occurred, the hydration status of the plants dropped to some extent and the sucrose concentrations of the juices increased. Age of the plant has great influence on this growth-response ability and, consequently, as the plant gets older the juices are improved regardless of treatment, although in their water content the tissues do maintain their relative positions with respect to their nitrogen treatments.

Many theories for the variation of sucrose concentration in juices have been propounded and presented in the past, but to cover them would hardly be feasible here. A thorough discussion of these theories is available in the technical report, Project D-1 at the Experiment Station. In the light of the findings in this series of tests, none of the older theories as discussed in our 1936 paper were satisfactory.

In spite of the fact that our knowledge is admittedly still very sketchy, we would like to present the picture of carbohydrate metabolism as it appears to us at present.

The number and volume of storage cells in a joint of cane depend on the growth conditions (determined by nitrogen, water, temperature, and so forth) at the time the joint was formed; number and vacuolar size of cells determine the total storage capacity or volume of the joint. Sugar is the primary construction material of these cells and their living contents. Cell wall materials thus represent a loss of potential stored sugar. To maintain life processes each cell uses up sugar for energy, thus presenting another loss of potential stored sugar. Associated with the living storage cells are the other non-living cell types needed to maintain and support the cell com-

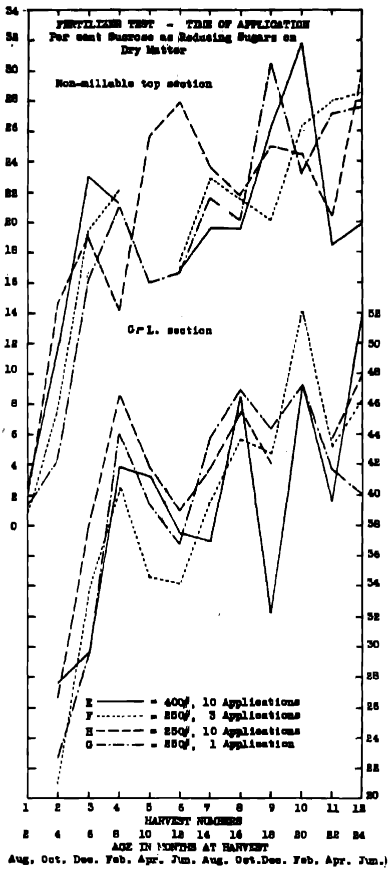


Fig. 19

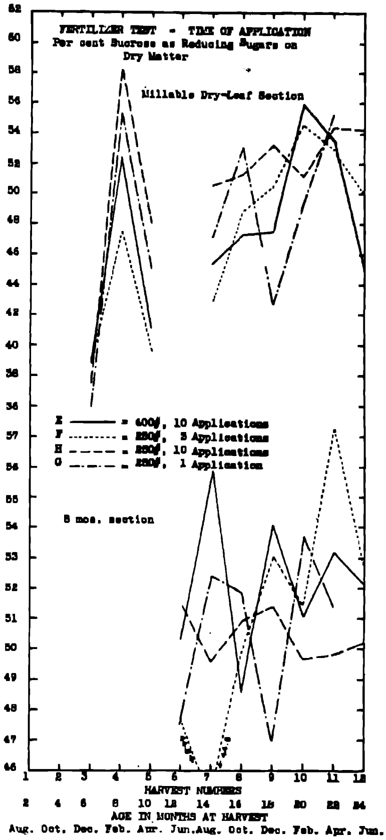


Fig. 20

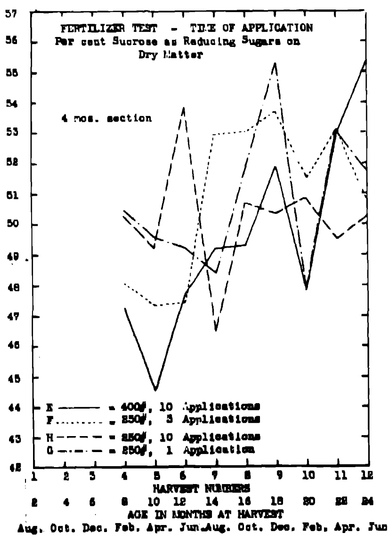


Fig. 21

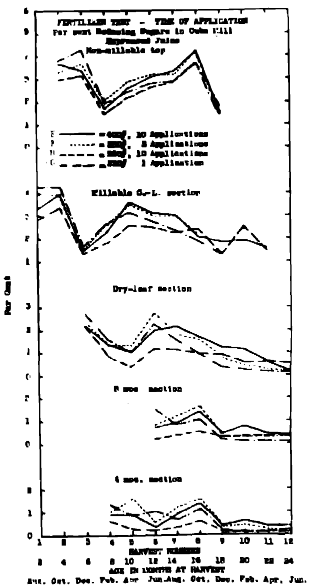


Fig. 22

munity in the stick; they also represent diverted potential stored sugar. Thus the sugar stored represents the difference between the amount available from the process of photosynthesis and the amount used up in cell construction and respiration.

In the analyses of samples of cane tissues or juices, reducing sugars are invariably found present. The amounts of reducing sugars present may well serve as a rough index of the growth rate of the cane plant, for during accelerated growth they are increased. Sucrose percentages in the plant are inversely correlated to the reducing sugar percentages although the relationships are rarely proportional, i. e., the losses in sucrose are not compensated for by, but are usually greater than, gains in glucose.

In plants other than sugar cane, glucose has been assumed to be the movable form of sugar, later on condensing to the more complex carbohydrates in the cells. With microchemical methods it has not been possible to identify reducing sugars in the fibrovascular bundles of H 109 cane sticks. Thus we are faced with one of two probabilities: first, that the sugar moving in these vessels was not glucose but sucrose (or some other non-reducing sugar form) and second, that if the sugar were glucose, i.e., simple reducing sugars, the mode of movement was of such a nature as to make it impossible to determine glucose by the methods which we employed. We did find, by microchemical methods, glucose to be present in appreciable quantities in the cytoplasm of storage cells and this fact may account for the considerable percentages of glucose found in expressed juices. In the light of these conditions we were led to the conclusion that reducing sugars present at any time in the mature stalk tissue largely represent the remnants from inverted sucrose which had been utilized in the metabolism of the cells. The higher the vegetative activity of the cell, the more energy it requires and consequently the more sucrose will be withdrawn from storage.

In older sections of the stick the rates of utilization of sucrose were lower and consequently less reducing sugars were needed to fill constructional or respirational needs. The storage space in the cells was also somewhat increased by a reduction in volume of protoplasm (and its absorbed water). Sucrose could be moved from the top into these matured cells and the sugar content of the section of stalk improved not only relatively but absolutely. With removal of nitrogenous compounds from the older cells for probable re-use in the region of the growing point, the protoplasmic contents of the cells, which are highly hydrated, lose some of their volume and activity, and sucrose can replace the withdrawn materials resulting in not only less water but more sucrose in the cell. The theory of a more-or-less-"static" cell, so far as total sugar storage is concerned, which was proposed by Das in 1936 is considered untenable and is now believed to be a "dynamic" cell, the storage capacity of which is fixed, as formerly, but the contents of which at any time are governed by the factors operative in promoting all phases of cell activity. In the joints of the green-leaf section and the recently formed dry-leaf section, the cells are younger and more active, with relatively poorer sucrose content per unit volume of cell storage capacity. Thus, primarily, improvement of juice quality is the problem of bringing the largest number of joints in the stick to the lowest degree of vegetative activity through the application of some limiting factor such as age, season, water, or fertilization, which may depress cell activity.

In the 1936 study nitrogen was tacitly blamed for increases in hydration. These hydration increases caused not only dilution of juices but also influenced the

mechanism of carbohydrate metabolism. At this time it is still felt that nitrogen is the causative factor, but it is now uncertain as to whether the sucrose is first inverted and used and then water enters the cells as replacement or, *vice versa,* if a concurrent combination of the two are operative.

More work is needed on the translocatory forms of carbohydrate in the plant to substantiate our findings regarding glucose in storage and fibrovascular tissues, for we realize that the quantity of a material to be found in the fibrovascular tissues is a possible function of the speed of movement or use of such material. The lower the amount which may be found present, the higher the postulated speed of movement must be to translocate a given mass through a small vessel. It may have been possible that we were confronted with this problem in our study of fibrovascular material and were not able to obtain visible chemical concentrations in cane tissues for that reason.

As already mentioned there is good reason to believe that the cell wall materials laid down in times of rapid growth, as contrasted with slow growth, are at least physically different and perhaps also chemically different and, *per se,* possess different water-holding capacities. As was proposed in the 1936 study, it is quite likely that inorganic salts influence this physical condition and that probably calcium is the largest contributor. Removal or replacement of excesses of this basic swelling agent which occur with advanced age could then influence the course of cell hydration and sucrose concentration, as our work seems to indicate.

In the 1936 test the data obtained seemed to point to interconversion from one carbohydrate form to another as a result of variations in the hydration status. The present conception does not completely obviate the former idea, but does considerably modify it to allow for changes in sucrose concentration which are too large to be accounted for by interconversion. As a matter of fact the data collected in this series of tests tend to relegate this sucrose-hemicellulose inter-conversion (if it exists) to an unimportant position as a factor for the variation of sucrose percentages and amounts in sugar cane.

Glucose (Figs. 22, 23):

As already mentioned, data for glucose, water content, and growth rates show parallel responses and in general are opposed to the curves for the sucrose concentration in the plant. If we assume that glucose in the stick were being condensed to sucrose for storage as well as meeting the needs of respiration, then at those times in the rapid-growing months when it occurs in highest amounts, we should theoretically find increases in sucrose concentrations—*which we most assuredly do not find.* If we assume that the glucose is increased in the summer due to conversion from both sucrose and hemicelluloses, we should find losses in both sucrose and sugar-free dry matter in a given section of stalk material. In this test we find, within the error of analyses, only reduction in sucrose. This reduction in sucrose is out of proportion to the glucose found at any time on an absolute pound basis in a given section of stalk, thereby indicating its removal or loss by respiration. It must also be remembered that at the same time sucrose concentration increases in older cane material, the cells in the same material become thicker walled, harder, and more lignified. If celluloses and hemicelluloses are to be considered functionally as

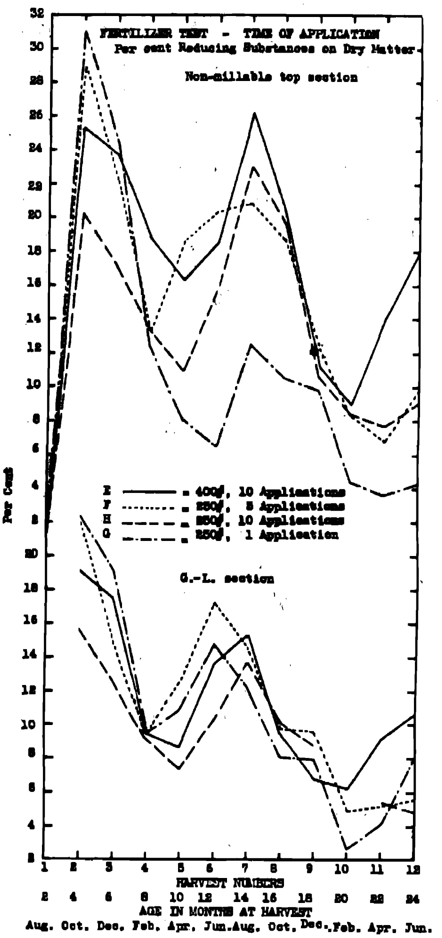


Fig. 23

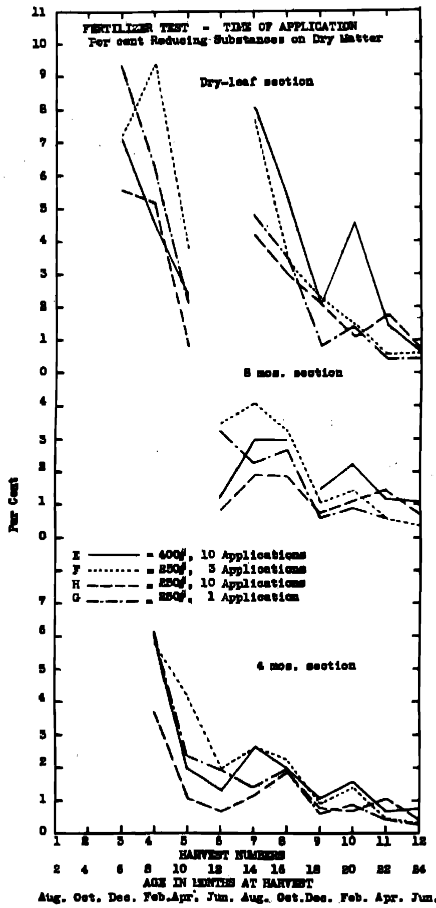


Fig. 24

cell wall materials, how is it then possible for the cell walls to become toughened, if fractional parts of them are being removed to satisfy the increased sucrose percentage in the cell—a condition which we do find with increased age?

The only reasonable explanation of this situation lies in the conception of the "dynamic" rather than the "static" cell. In the case of the dynamic cell there is a continual flow of sugar from the leaves to build mature cell walls, to satisfy respiration losses, and to attempt to maintain "normal" sucrose storage in the cells. Only on this conception of the living cane stick do all facts fit together. When growth and respirational demands under seasonal or fertilization stimuli interfere with the flow of sugar downward from leaves, losses in stored sucrose are encountered in the lower portions of the stalk due to the metabolic demands of the plant parts adjacent thereto. When the growth demands drop, through the effect of any limiting factor becoming operative, the leaves can then meet local consumption demands in the apex, and any excess sugars formed go to the replacement of losses formerly sustained in the older parts of the stick.

If it is possible to apply knowledge gained from other plants to the cane plant, respiration rates and growth respond to the same stimuli. The demands for sugars made by increased respiration in times of good growing conditions further accent any shortage of the supply coming from the leaves. Thus, using glucose as a respiration index, we have a useful weapon to apply in measuring the maturation of a given section (or whole stick) since, while it does not represent sucrose losses quantitatively, it does measure relative rates of loss or indirectly the ability of the cells to use stored or incoming sugars.

Electrical Conductivity of Juice (Fig. 25):

In the 1936 report the conductivity figures were employed as a measure of the ash materials in the plant saps, since this method had been accepted by plant physiologists in general as satisfactory. From the data of this present test wherein the conductivity of juice as well as the percentages of ash in the tissues were determined, we have come to look askance at the validity of the conductivity data for ash measurement. As a matter of correction of the 1936 conclusions, it appears that increased applications of nitrogen do not cause an increased concentration of ash, but just the opposite. Thus it appears now that the increased conductance found at that time in the high-nitrogen plots, especially in the mature cane sections, was due to accumulations of acidic radicles of which no small part was probably organic. The increase of acidity and conductance of the saps with age, accompanied by a decrease in per cent of basic ash constituents in the same sections, can only point to a piling up in old tissues of acidic-type materials. It is to be regretted that chlorides, sulfates, silicates, and phosphates were not determined, as it might have been possible to localize the preponderance of the effect in the organic or inorganic acid classes as the case may have been. There is a strong possibility that a buffering action of organic on the inorganic acids may also have taken place. This would allow the conductivity figures to indicate differentiation, as they do, while at the same time masking any possible treatment differences on the pH of the same juices.

The conductivity measurements of juices when compared with the pH measurements lead one to hypothesize that there is a greater quantity of organic acids in plants fed with prolonged or high-nitrogen applications. As far as we know, no one has analyzed juices quantitatively for chlorides, sulfates, phosphates and so forth, nor has anyone tried to correlate quantitatively these acid constituents with the basic constituents. Ayres has collected data from this series of tests which point to a removal and loss of ash materials from the plant in the leaf as it is abscissed. Are the inorganic acidic radicles also removed from the plant by this mechanism or do they tend to accumulate with age in the plant? It would seem reasonable to suppose from our pH data that some of the inorganic salts on entering the plant would be decomposed, thereby releasing inorganic acid radicles which were either absorbed on colloid surfaces, or entered into combinations with organic materials in the cells and so were accumulated (but buffered in effects on pH).

Another factor in comparisons of total ash and conductivity must be remembered, and that is that conductivity will measure ash constituents in a soluble ionized condition only, whereas total ash will measure additional mineral material

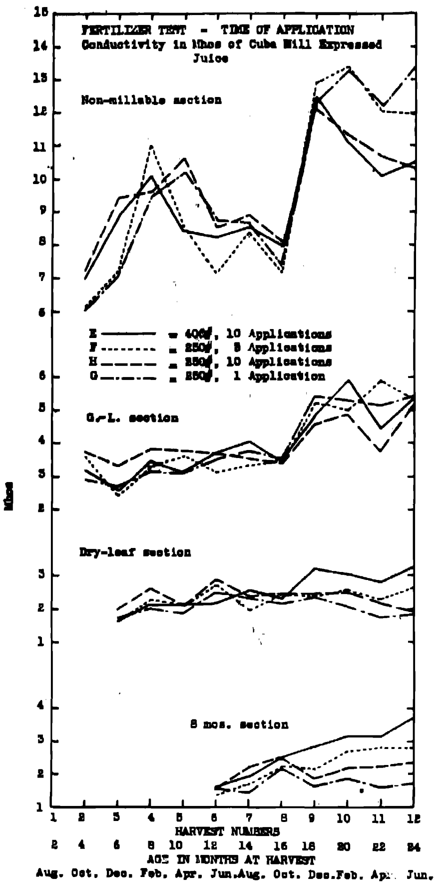


Fig. 25

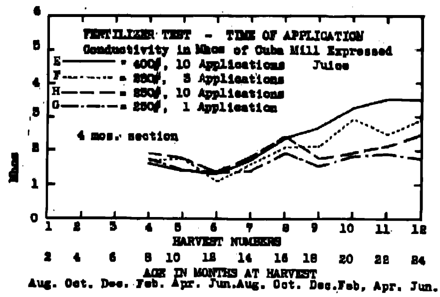


Fig. 26

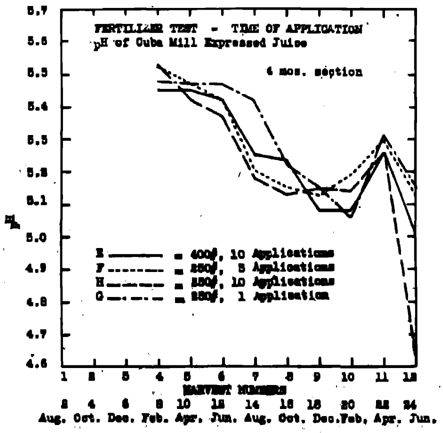


Fig. 28

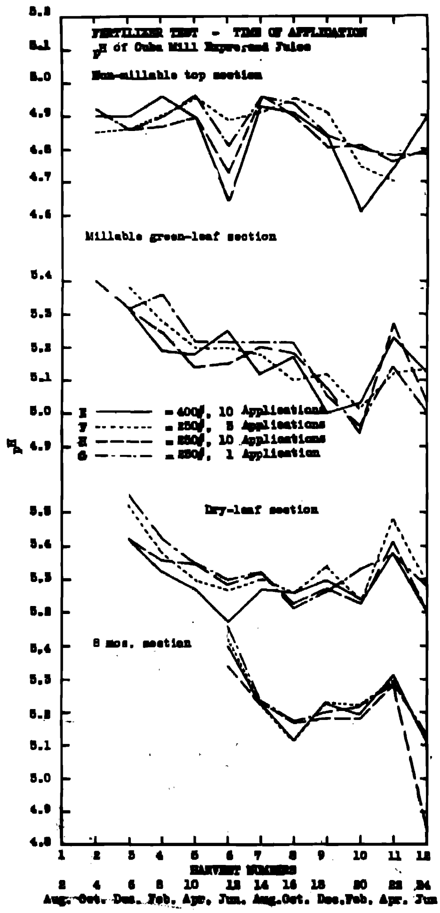


Fig. 27

built into cell structures and largely insoluble (except after ashing or hydrolysis by acids).

The non-millable top shows large seasonal variation in concentrations of electrolytes but no fluctuations due to treatment. The tops formed during the winter show high concentrations of electrolytes whereas in the corresponding summer-formed tissues the concentrations are low. In mature dry leaf, 8-month and 4-month sections there is only a slight seasonal trend in such concentration but there are good trends due to age and treatment, especially in the last part of the crop life. Hydration of tissue decreases steadily in the older mature sections and may account for part of, but probably not all, the apparent increases in salt concentrations in juices. The unaccounted-for salt increments in the juices are present in greater amounts in the higher nitrogen treatment and when the nitrogen applications are prolonged throughout the life of the crop.

In general, Ayres' determinations of ash in these canes indicate a directly opposite set of conditions so far as per cent total ash in *the plant* is concerned. As a consequence of this, it must be inferred that the functions of the ash constituents within the plant, and possibly their location in the cells, may vary with the nitrogen metabolism level of the plant, for at least it appears that their physico-chemical properties are different.

Samples of cane juice from the Cuba mill were electrodialyzed and some qualitative tests were run on the resultant solutions. As would be expected considerable quantities of chlorides, sulfates, and phosphates were found to be present in the acid chamber; ammonia, calcium, potassium, magnesium and some form of organic nitrogen (which was not free ammonia but which readily decomposed at high pH to yield ammonia) were found to be present in the basic chamber.

The undialyzable residue of sugars, proteins and other compounds of large molecular size yielded a solution which was highly acidic. On analysis for total nitrogen this solution yielded about one eighth to one third of the nitrogen in the original juice. The soluble, ionizable ash constituents were almost completely removed from this fraction. We found that the electrodialysis of even the thick, heavily discolored saps from the cane tops yielded beautifully clear juices. Apparently due to the relatively more rapid removal of basic materials in electrodialysis, the solutions passed through acid isoelectric points of the proteins and suspensoids which were soon flocculated and precipitated in a curdy mass leaving the juices in a clear state. The conductance of these dialyzed juices was greatly reduced and approached the figures for sugar and water solutions of the same concentration. Because we did not obtain neutral solutions in the center (or dialyzed juice) cell we suspect the presence of a set of large molecule acids.

The electrodialysis method should be investigated further at some time as it may be an approach to the separation of adsorbed ions from the colloids of the cell, or at least an approach to a method of separation for the study of nitrogen fractions which are not in the protein or polypeptide groups (large molecules).

As can be judged, we know little or nothing as to storage forms of nitrogen in the plant, chiefly due to a lack of methods of separation which will not involve decomposition enroute to quantitative determinations.

pH of Cuba Mill Juice (Fig. 27):

There are no discernible treatment differences in the acidities of juices of the various treatments at any harvest or age. There is, however, the same gradual decrease in pH (increase in acidity) with increasing age of a given section of stalk or of the stalk as a whole.

The acids were not fractionated nor was the total titratable acidity obtained, so that it is not known to what group of acids or compounds (organic or inorganic) the increased acidity is due, or where, within a cell or community of cells, the compounds which are responsible may be located. Under "conductivity" a discussion was presented dealing with the possible organic origin of this acidity. It must not be forgotten, however, that when the juices were electrodialyzed, chlorides, sulfates, phosphates (and probably some silicates) were obtained. The latter two acids form complex salts yielding one, two, and sometimes three hydrogen ions in solution which can easily affect the acidity.

An attempt was made to determine pH in living tissue by using intravita range indicator dyes and a microscope. The cell walls and the penetrable lamellae of the cytoplasm all gave reactions closely in accord with the pH of juice data, but it was not possible to determine the pH of the stored sucrose or vacuolar saps. In cases where the cell was "killed" (during or after staining) either an increase or decrease in pH would be effected. Due to the impermeable interfaces established in the cytoplasm of the living cell, it was not possible for the large molecule dyes to penetrate these "living" colloidal membranes into the vacuolar storage cavities.

The acid reactions of cell wall material and cytoplasm, and the increase in acidity of juices with age, perhaps arise from increases in adsorbed organic acids which are themselves derived from sugars used in respiration. However, the question is still wide open in all of its phases and will probably remain so until such time as the physical properties of the cell colloids are better understood.

In studying the conductivity curves along with the pH curves there appears to be higher adsorption of ions in the higher nitrogen treatments and in plots continuously fed with nitrogen (where cytoplasm is somewhat more bulky when viewed microscopically). This adsorption may be the mechanism by which buffering of acids arising in respiration is effected, i.e., they are bound in a partially un-ionized condition, thus accounting for the lack of differentiation of pH between treatments for a given age of plant.

General Observations:

In general we feel safe in stating that the cell community in a joint can never be considered static; changes are continually taking place up to the point of "death" (not to mention afterward) of all cells in a stick.

As an example we found that with increase in age there was more and more a deposition of lignin-like compounds in and around fibrovascular tissue—a hardening of the fibers, so to speak, up to the time of tasselling. After tasselling, however, there was a sudden change in the activity of these cell groups from deposition to that of removal. Lignin is known to be one of the most stable constituents in a plant cell, samples estimated at over half a million years in age having been found unchanged chemically. So far as we can find there is no enzyme known which is

effective in splitting lignin. Yet quite definitely, as a result of tasselling, much of the lignin was lost from the fibrovascular tissue, causing the bundles to become more flaccid than formerly. The rind became softer and was more easily penetrated because the tissue remaining, after the decrease in lignin (due to tasselling), was mainly cellulosic in character.

How is the plant able to move the lignin and to where is it moved? In general, considerable amounts of lignin (along with considerable amounts of silica) were found, through microchemical methods, to be present in the tassel arrow. The lignin may have been moved there; if so, the *mode* of movement of both these materials remains a wide-open question.

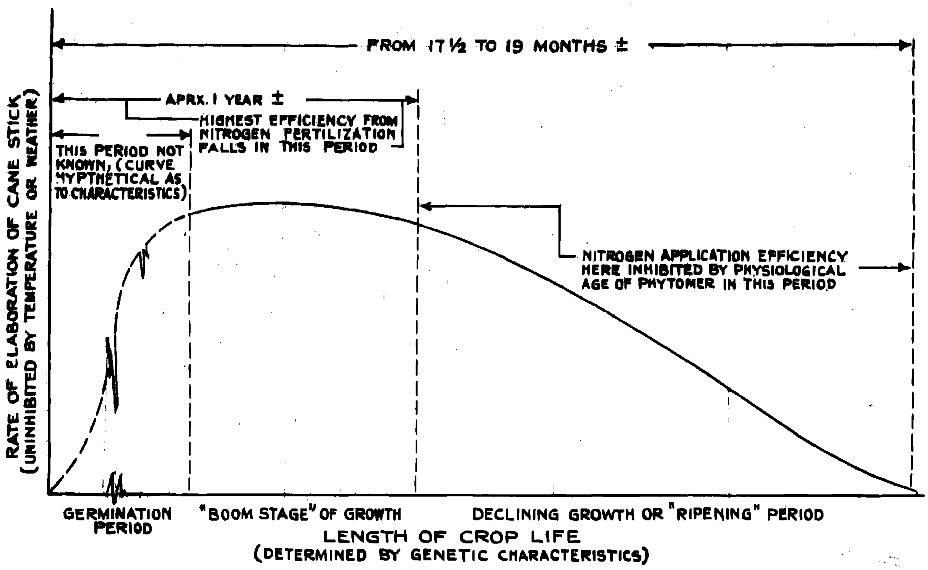
The change in lignin status, due to tasselling, was effective throughout the stalk, from the apex to the very butt regardless of the length of the stick. The writers have been able to distinguish between tasselled and untasselled stalks from butt sections of the stalk alone, even in some unfamiliar varieties and hybrids. This condition dealing with the lignin of tasselled and untasselled stalks has already been investigated and reported by D. M. Weller, Project P–13 at the Experiment Station.

Discussion:

It becomes apparent that the effect of nitrogen fertilization on the sugar cane plant, all other plant growth factors being non-limiting in magnitude, is controlled by two major conditions: (1) weather (particularly sunlight and temperature), and (2) physiological age of cane.

Under differential nitrogen applications, the quantitative responses in H 109 cane and sugar yields to be expected have become evident only when the average of the day and night temperatures is above a minimum of 67° F. Below this average temperature growth does not cease but no large acceleration in elongation due to nitrogen fertilization is obvious. This temperature of 67° F., it will be noted, is an *average of day and night data* and must not be confused with the 70° F. base of the Das' day-degree method of evaluation wherein the diurnal maximum temperature is used regardless of its duration. It is obvious that there was a *maximum temperature of 70° F. or over* for us to arrive at a 67° F. average of day and night temperature when we have a six to seven degree diurnal-nocturnal range at Makiki. In other words our findings regarding average temperatures and growth rates upholds Das' day-degree base of 70° F. maximum temperature from which an approximate straight-line correlation of growth with temperature may be calculated. An average day and night temperature of 67° F. seems to be the exact point at which accelerated responses due to nitrogen treatment first become evident in H 109 cane (and 31–1389), and for this reason we feel it worthy of mention. While we have no data to support the theory, observation would indicate that this threshold temperature will be different for different varieties of cane.

Our data point to the normal growth-rate curve of cane, when uninhibited by weather or season, as being an inverted parabolic curve, the spread of which on the time axis is controlled by genetic characteristics. The curves presented below theoretically approximate the picture as we see it for non-tasselled H 109 stalks.



The timing of applications of nitrogen to the soil is governed by three factors: (1) the capacity of the plant to take up and hold in reserve nitrogen supplies for use in subsequent tissue formation, (2) the ability of the soil microorganisms and colloid complex to furnish nitrogen to the plant from soil "reserves" and from the applied fertilizer, under variable conditions of soil temperature, and moisture, and of microorganic activity, and (3) the weather conditions available for growth.

The first factor, capacity of the plant to hold nitrogen reserves, is a matter of the volume of plant material and the concentration of nitrogen which we are able to pour into this capacity without toxic effects. It must be borne in mind that anatomical parts differ widely in capacity in this regard. There is also considerable genetic difference in storage ability among varieties which will have to be watched.

In all our tests we find that the cane plant, under conditions of either nitrogen excess or deficiency, holds very close to a common range of nitrogen content, indicating that storage leeway per unit volume of plant tissue may not be very wide. Excessive amounts are definitely not taken up by the plant. This indicates some sort of either organic or inorganic fixation in the soil, or losses through leaching. *Thus with limited storage space in the plant, nitrogen must be quantitatively applied to correspond to the plant volume available.* In other words we should graduate our fertilizer applications according to the size and number of the stalks in the field and apply the nitrogen within the boom stage, taking into account the time lag between application and complete uptake, and the lag between uptake and completion of resultant growth. We have found the uptake period to be about three or four months for normal applications under good growth conditions at Makiki. The resultant prolongation of growth is generally proportionate to the amount taken up.

As to the second factor, the ability of the soil complex and soil microorganisms to feed nitrogen supplies to the plant, we have hardly scratched the surface of the subject. At Makiki we know that the soils involved in these tests had a more or less constant available nitrogen content of from 12 to 17 pounds per acre, as measured by RCM, after the first flush of nitrogen in the fertilized plots had been

lost. This seems to be the general nitrogen status of Makiki soil whether fertilizer is applied or not. The picture seems to be a sort of equilibrium between available and non-available nitrogen reserves, which is a characteristic of the soil type and environment.

The growth obtained in a zero-nitrogen plot shows this to be the condition, even if absolute figures are in error from year to year or season to season. We are at a complete loss as to whether this nitrogen arose by release from the soil complex by chemical, or biological action (or both), or was a photochemical fixation.

We do know in our case, however, that drying off of the soil, fallowing, and increased soil temperatures, increased the available nitrogen to a certain extent. By analysis it was found that the nitrogen applied to the soil was either taken up, fixed, or otherwise lost, within a period of three and one half to four months from time of application.

The data from the single-application treatment indicate that the Makiki soil nitrogen release is too slow, and not sufficient in total amount to maintain ideally the plant at any time under the growing conditions here. When nitrogen is supplied in one early application, that which gets into the plant plus that which later comes from the soil is not sufficient to carry a crop over 16 months of active growth. These facts point to a tie-up in the soil-to-plant transfer of nitrogen, either chemically or biologically, *which inevitably means losses where excess nitrogen is applied at one time and not graduated to the plant's size and age.*

The weather conditions available for growth of sugar cane have been covered in the various papers by Das, Clements, and others. It is mentioned here because it appears that below certain limits of temperature any large responses due to nitrogen differentials are lost. When the soil fixation or "loss" factor is considered, it is certain that much of the fertilizer, applied when the plant has not sufficient time to efficiently assimilate all of it during the ideal growth period, will be lost.

In other words we found that nitrogen should not be applied to H 109 cane grown at Makiki under the conditions of this test, just before the onset of seasonal conditions which are expected to depress growth.

Taking into consideration the normal starting times for crops in Hawaii, we are faced with the fact that the temperature curves and the ideal growth curves for cane are bound to collide sometime within the first nine months of the crop life to the disadvantage of the growth. It becomes readily apparent that a compromise fertilization schedule must be adopted, so as to apply the fertilizer at the proper age in the proposed crop life (which includes the maturation period) to take advantage of the better growth periods. By this means it will be possible to bring the largest part of the stalk to a state of ripeness (or vegetative dormancy as we now visualize it) through an induced nitrogen shortage and age.

For economy's sake in extremely short crops one application seems ideal, whereas for long crops two or three applications are advisable. *The important problems involved in fertilization are really the problems associated with the avoidance of excess nitrogen fertilization for the weather conditions under which the crop is expected to grow, rather than the problems dealing with specific nitrogen deficiencies.* Plantations, as a rule, do not complain of juices from slightly nitrogen-deficient fields, though cane tonnages may be depressed somewhat at times. In the race for greater tonnages of cane, quality of juices are sacrificed *too often* for quantity.

Plant tissues from any anatomical part, although at times apparently suitable, cannot always be used as satisfactory indices for fertilization because the nitrogen percentage so determined is only indicative of the plant content and does not indicate what the soil may release under the variable, seasonal, light, moisture and temperature conditions during the ensuing life of the crop. Drought apparently causes fairly large increases in available nitrogen in the soil and, when water becomes available, part of this soil supply is taken up by the plant for further growth, causing a resulting upset in plant percentages not only of nitrogen but also of sugar. Thus under irrigated conditions soils will tend to follow a smoother nitrogen-content curve than they will under unirrigated conditions.

On unirrigated plantations soil nitrogen should be watched at the same time tissue content is, or excesses may be applied when they are not needed and are not assimilable by the plant due to too low soil moisture. Later, when water does become available, heavy growth ensues and juices are depressed in quality.

As will be brought out in a later paper dealing with the effects on three different varieties of cane, growth habits primarily of genetic origin rather than of treatment heavily influence nitrogen fertilization practices on different varieties; this points to the necessity for study of water and nutrient requirements for each individual variety. The applications to a new variety are usually those applied to an old familiar standby even though the two may bear little relationship to each other genetically or otherwise, except that they are sugar canes.

As our new cane varieties bring wild, vigorous, new strains into the picture, with relatively high response to season and weather stimuli, as well as efficient use of nutrients to promote vegetative responses, more and more will we have to avoid excesses of nutrients of all sorts, so as to be able to avoid the peak seasonal growth and respiration effects on stored sugars and sugar storage. These points will be brought out in a later paper.

What we are emphasizing here is that the sucrose storage rate is inversely related to growth and respiration rates regardless of what variety, location, or treatment we consider.

The plantation manager's problem is to adapt his fertilizer policy to give the best compromise between the three rates as established by the weather, environment, and variety. If he were to fertilize to get optimum yields in average years, when normal weather conditions act as a check to excessive growth, and then should get abnormal growing temperatures, the juice quality would be affected.

So far no satisfactory method of weather prediction is available for two-year periods, so actually the plantation manager has little recourse but to apply his normal experienced optimum fertilizer application and trust for the best. The timing of the applications allows him some control over the type of vegetative growth and the length of life of his crop, but this is also largely at the mercy of the weather.

Midway Islands

By Fred C. Hadden

Very near the center of the North Pacific Ocean there is a coral atoll or circular coral reef in which there are two small islands. This reef and the two enclosed islands are called Midway Islands, or simply "Midway". They were discovered in 1859 by Captain N. C. Brooks who took possession of them for the United States of America.

Midway—The Middle

If one will look at a map, he will find that Midway is in the middle of the North Pacific Ocean. Not only is it in the almost exact center of the North Pacific Ocean, but it is also halfway around the world from Greenwich, at which point our time begins. Midway is about 300 miles north, and 900 miles west of Honolulu. It is not in the tropics, nor is it a "South Sea Island." Distances from Midway to other parts of the world are approximately as follows:

Midway To:

Johnston Island	S.E.	1,000 miles	San Francisco	E.N.E.	3,200 miles
Honolulu	S.E.	1,300 "	New Guinea	W.S.W.	3,400 "
Wake	S.W.	1,200 "	Alaska	N.N.E.	2,000 "
Kamchatka	N.W.	2,000 "	Shanghai	W.	3,600 "
Canton Island	S.	2,200 "	Samoa	S.	2,800 "
Aleutian Islands	N.	1,600 "	Australia	S.W.	3,800 "
			Japan	N.W.	2,600 "

Sand Island, the larger of the two islands in the south side of the lagoon, was colonized in 1902 by the Commercial Pacific Cable Company. At that time there was no vegetation on Sand Island—it was nothing but a blinding glare of white, shifting sand, inhabited only by several million sea birds. However, the other island in the lagoon, now called Eastern Island, was even at that time fairly well covered by Scaevola, wild grasses, and Boerhavia. The roots of Boerhavia furnished castaways on Midway their only vegetable food, and it very possibly prevented death from scurvy.

Many passengers passing through Midway ask: "How old is Midway?" Geologically speaking, the atoll is probably very old, possibly 100,000 years or more —perhaps millions of years old. There is no way at present to determine how old it is. However, the atoll is a coral and sand platform resting upon what must be a very old volcanic mountain top, with the living and dead coral exposed in a ring at the outer edge of the reef in a somewhat circular barrier which breaks the force of the giant waves from the open sea. Waves inside the lagoon are rarely more than 2 or 3 feet high. However, great waves from 20 to 30 feet high often break on the outer reef during winter months in stormy weather. As they break on the reef the spray sometimes flies upwards for from 50 to 100 feet.

Geological Formation

The reef was very likely formed as follows: A million years ago, or more, lava began to erupt from a weak place in the earth's crust on the bottom of the ocean. As more and more lava poured out it built up a great volcanic cone that may have emerged from the sea to a height of several hundred or even several thousand feet above sea level. From sea level to the bottom of the ocean at this point is about 12,000 feet or well over 2 miles. The small part of this volcanic mountain which was exposed above the sea was worn down by the action of waves, or perhaps by the great ice cap that may have moved this far south during the ice age (possibly 1,000,000 years ago). The land was worn down to, or even a little below, sea level at that time. Eventually the ice cap melted, slowly raising the sea level as the ice disappeared. Then both coral-building animals and plants began to grow on the submerged mountain top, until the lava was buried under hundreds of feet of coral rock. We do not know how far down we would have to drill before the lava rock would be reached. At first the coral probably formed more or less uniformly on the flat-topped lava rock. Later it grew more rapidly on the outer edges of the reef, and thus built up a ring of coral. Then the sea subsided a little so that this outer ring of coral was exposed above the surface of the sea, as it is now, leaving an irregular shallow lagoon inside the reef. The deepest water inside the lagoon is only 60 feet, and the average depth is about 8 feet.

Then the action of waves and wind built up the small island of broken coral, shells and sand which is now called Eastern Island. Later on under somewhat different conditions another island was formed of sand only. This is now called Sand Island and has been colonized by the Cable Company and by Pan American Airways.

Eastern Island, being the older island, has had vegetation on it for hundreds of years. Because the island is constructed of coarse pieces of broken-up coral, shells, gravel, and coarse sand, it is very porous, and the water there is quite brackish, containing much salt from mixture with sea water. However, donkeys that were turned loose on Eastern Island managed to survive by going down to the edge of the beach, where they pawed holes in the sand and drank the water which trickled out into these holes. This is a mixture of rain water and a little sea water, brackish, but just barely sweet enough to support life.

In 1902 when the Cable Company first started operations at Midway, Sand Island was a level waste of wind-blown, glaring sand, with only a very few bunches of grass, one or two small Scaevola bushes, and a few Boerhavia vines growing in widely scattered locations. There was one large sand dune about 30 feet high where the Cable Company light is now situated, and the rest of the island was only a few feet above sea level. The Cable Company planted San Francisco grass, *Ammophila arenaria*, and hundreds of ironwood trees around their compound. After a few years the trees were large enough to protect the rest of the north end of the Island from the terrific wind storms which come intermittently throughout the winter months. This allowed the San Francisco grass, Scaevola, and Boerhavia to spread rapidly, so that 20 years later sand dunes 10 feet high had formed around the Island. Every place a Scaevola bush had got a good start it formed a dune as the sand accumulated in and around it. As the sand filled in the bush kept

growing, and more sand was collected among the branches, so that now some of the dunes are 30 to 35 feet high, with just the tops of the bushes appearing above the sand.

Because the sand is finer on Sand Island, it holds rain water better than Eastern Island, consequently the ground water on Sand Island is only slightly brackish. This almost-fresh water is held up in the Island by pressure from the sea water, which is denser or heavier. It has only a slightly salty taste, but does have a rotten egg odor—due to the hydrogen sulphide which comes from the millions of eggs that broke or rotted on the Island, and also from bird guano, and the remains of the millions of birds that have died there. Many thousands of birds die every year, either from disease or from starvation. Flies breed in these dead birds, and at various times of the year they are very bothersome. Small white crabs, that live in holes in the sand all over the Island, also eat the dead birds.

Shipwrecks at Midway

For some strange reason Midway has acted as a magnet, attracting ships to it and then wrecking them. More ships have been wrecked on Midway than on any other leeward island of the Hawaiian group.

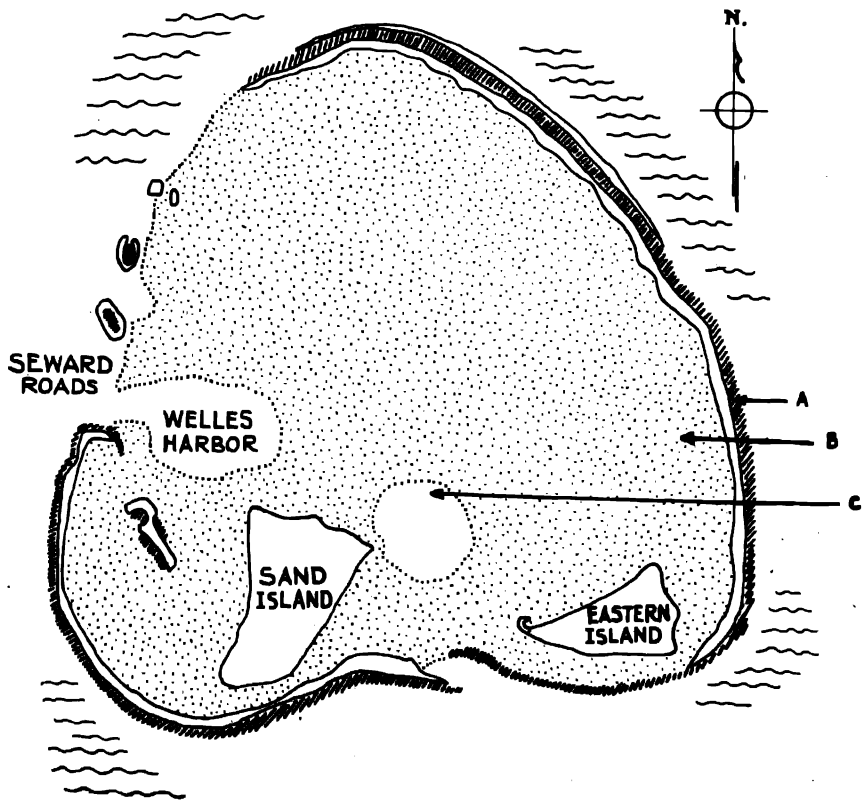


Fig. 1. Map of Midway Islands prior to improvements: A—coral reef, mostly submerged; B—shallow water in lagoon; C—deep water in lagoon.

The "General Siegel" with Captain Jacobsen in charge was wrecked at Midway during a storm on November 16, 1886. Immediately many weird things began to happen. First one of the sailors named Larkin had his hand blown off while fishing with dynamite, and a few days later died complaining of great pain in his stomach. Another sailor named Brown accused the captain of poisoning Larkin. Then Brown and Captain Jacobsen went over to Eastern Island, but the captain returned to Sand Island alone, stating that Brown had accidentally killed himself.

Jorgensen, another sailor, then went with the captain and a German boy to Eastern Island and the captain showed them where he had buried Brown. The captain stood by indifferently while they dug up Brown's body—and found a bullet hole in the back of his head!

Several days later the captain and Jorgensen went again to Eastern Island and Jorgensen returned alone to Sand Island, saying the captain had disappeared! The captain was never seen again.

Jorgensen's shipmates outfitted a boat which had drifted from the wreck of the "Dunnottar Castle" on Kure or Ocean Island, 60 miles northwest of Midway, and sailed for the Marshall Islands, leaving Jorgensen marooned and alone on Midway. They had accused him of killing the captain and were afraid to take him with them. He remained alone on Midway for nearly a year, until the "Wandering Minstrel" arrived.

Fig. 2. Captain Walker's house on Sand Island (1888).

On February 8, 1888, the "Wandering Minstrel," commanded by Captain F. D. Walker was wrecked in Welles Harbor—all hands including Captain Walker's wife and three sons got to shore safely in small boats.

On October 13, 1888 (Saturday), John Cameron, Adolph Jorgensen, and a Chinese boy named Moses, left Midway in a small boat. On November 25, 1888, after a voyage of 43 days, they landed at Mille Island, 1540 miles from Midway.

George C. Munro has very kindly loaned me the photographs taken at Midway in 1891 by one of Mr. Walker's sons. These pictures show the house occupied by the Walker family after they were shipwrecked at Midway in 1888. In the photograph showing the Scaevola bushes forming sand dunes to the left of Walker's home may be seen some of the huts occupied by the other castaways. They barely show at the extreme left. Another picture shows the huts of the men on Eastern Island where there was more vegetation.

According to Mr. Munro there were no goonies, boobies, or bosun birds on Sand Island at this time (1891), and only one or two small colonies of sooty terns were nesting at the other end of the Island. Apparently all the goonies, bosun birds, and moaning birds had been eaten by the castaways!

Fig. 3. Castaways' huts—above, on Eastern Island; below, on Sand Island (1888).

The sloop "Helene" was wrecked on Sand Island during a northwest storm (date unknown); she brought to Midway the crew of the bark "Kellogg" which had been wrecked on Dowsett Reef.

Saved by a Toe:

About two o'clock one morning in December, 1903, the schooner "Julia Whalem" struck the north rim of the reef "bow on." The life boat was lowered and the crew scrambled into it. They discovered they had no oars, so climbed back aboard the schooner to look for some but none could be found. The only thing they could find to use as oars were brooms, and these were used to row around the reef into Welles Harbor, and to shore at the Cable Company dock. Not only were there no oars but the boat started to fill with water and sink. They then discovered that there was no plug for the drain hole in the bottom of the boat. Happily they found that one of the "kanaka" sailors had a toe big enough to satisfactorily plug the hole and this saved the day. The ship broke up and sank two hours after striking the reef.

The Anchor on the Southeast Reef:

On Christmas Eve, 1906, the bark "Carlton" went aground, "bow on" on the southeast reef. Apparently they threw the anchor overboard in order to hold the ship on the reef and keep it from sliding off backwards and sinking in deep water. The anchor is still there and shows plainly in calm weather. The captain and crew took to the boats, and rowed around the reef and into Welles Harbor to the Cable Company dock. Three trips were made, each time salvaging as much cargo as they could. A few days later a southwest storm came up and on New Year's Day the ship broke in two and was demolished.

According to A. R. Tinker, a Cable Company employee, at that time there were no ironwood trees on the Island, and very little plant life of any kind, so the wreck could be plainly seen from the second floor of their quarters at the Cable Company. The ironwood trees were planted in 1907. In 1940, 33 years later, the trees were from 60 to 70 feet high.

The Commercial Pacific Cable Company

In order to maintain and operate a submarine cable across the Pacific it was necessary to establish a relay station at Midway.

In 1902 the Cable Company landed on Midway and started the construction of their compound on Sand Island. All the material and equipment had to be brought ashore in whaleboats and lighters. It was a long haul from Seward Roads or Welles Harbor in to shore, or in through the treacherous S-shaped, small-boat channel in the south rim of the atoll. In those days everything had to be moved by man power—it was really tough.

However, they did build substantial steel and concrete buildings, water towers, windmills, a very large concrete cistern for fresh water storage, a steam ice-plant, a dock, and everything needed for operating the cable and for the comfort of the men stationed there.

Four times a year, for 15 years, 150 tons of soil were brought to Midway, and after that 2½ tons were brought in on each supply ship. It is estimated that over 9,000 tons of soil were imported for use in the 3-acre vegetable garden, and to scatter around on the sand for lawns to keep the sand from blowing out from under and around the buildings.

San Francisco grass and hundreds of ironwood trees were planted for protection from the winter storms. They now have a little paradise of their own, with ducks, chickens, turkeys, pigs and cows. The vegetable garden supplies them with fresh vegetables after the supply brought in once every three months runs out. Most of the men stay for a year or two—some stay longer.

Only the chief and his assistant could have their wives on Midway. Often for many months at a time there was only one woman on the Islands, at other times there were no women there. The inhabitants led a calm and peaceful life, disturbed only by a slight flurry when the supply ship arrived.

Pan American Airways

In 1935 the first expedition of the P.A.A. arrived at Midway and began to "dig in." They too had all the difficulties of unloading equipment and building materials from the ship on to lighters which had to be towed to shore, then unloaded

Fig. 4. Pan American Airways' quarters. Trees shown in top photograph are one year older than those in the lower picture.

and the materials reloaded on to sleds which were hauled up to position by a Diesel caterpillar. That "cat" has moved many thousands of tons of cargo—all the building material, and thousands of drums of gasoline each weighing about 450 pounds. It is still running.

The P.A.A. set up quarters for the men, a fine hotel for passengers, a power plant consisting of 3 large Diesel motors and generators, 2 windmills with tower tanks, and twenty 4,000-gallon steel tanks for the storage of rain water caught on the roofs of the buildings.

Thus a modern little town was set up within 7 or 8 months' time, with electricity, running hot and cold water (sun heaters), modern plumbing and nearly all the comforts of home.

Instead of waiting 3 months to hear from home, the Cable Company personnel received mail once a week—and how they complained if the plane was delayed a few days by weather. It is amazing how much cargo, besides mail and passengers, is brought to the Island on the planes.

On nearly every ship hundreds of pounds of fresh milk and cream, eggs, vegetables, fruit, and local express are unloaded at Midway and Wake, and even Guam. Once a week the plane also brings a new "movie" for our entertainment. Two dozen potted palms, each weighing 20 to 30 pounds, were brought here by air.

Fig. 5. Ironwood trees on Sand Island showing one year's growth.

Grass and ornamental plants supplied by the Hawaiian Sugar Planters' Association have been planted around the hotel, as well as trees for protection from strong winter winds. Ironwood trees planted 4 years ago are now from 25 to 30 feet high.

Only the "old-timers" who saw the place as it was at first can now appreciate all the work that has been done here.

Entomological Inspection

On November 24, 1936, the Philippine Clipper, a Martin flying boat, left Honolulu at 7:15 a.m. with the writer aboard. We had perfect flying weather, the visibility was unlimited, and a fine view of Kauai and most of the other islands was obtained on the way to Midway. It was about 6:30 p.m. when Midway was sighted, and it was completely dark when we landed by the aid of night landing lights.

Mr. Clark, the hotel manager, showed me to my room in the radiomen's quarters. It is small, about 8x10 feet, but cozy and comfortable, with a good bed, electric lights and heaters, chair, dresser and wardrobe. Later a small laboratory was made for me on the front screened porch of the quarters.

The next morning we were all up again at 4:30 a.m., long before daylight, in order to prepare the plane for the flight to Wake. The baggage and food were taken to the dock in "banana wagons" or station trucks, then loaded into the launch and taken to the barge, transferred to the barge and then stowed away in the proper places on the plane so as to maintain the "C.G.", or center of gravity, at the proper spot in the plane. At this time the plane was given its second entomological preflight inspection in order to find the insects killed by the spray treatment given the plane upon arrival. Dangerous plant pests and mosquitoes are sometimes found dead at this time. The plane was also carefully searched for insects upon arrival. From 15 to 20 insects, consisting of 5 or 6 species, are frequently found during this inspection. In one case over 1,000 insects were found on the plane; very rarely are no insects found. About 200 species have been found on the planes arriving at Midway. Most of them came from Honolulu, Wake, Guam, Manila or Hong Kong. Many of them are species not found at Midway, in Honolulu, or on continental United States.

One important insect pest that is prevented from reaching Honolulu and the U.S. mainland from the Orient by the spraying of the planes at Midway is the Anopheles mosquito, the carrier of malaria. If this mosquito and malaria should become established in the Hawaiian Islands, human efficiency would be cut down and hundreds of thousands of dollars of damage would result. There would even be a number of deaths due to malaria, and certainly the present high level of health would be lowered.

Sugar cane pests as well as other plant pests, such as beetles, bugs, moths, grasshoppers, flies, crickets, earwigs, etc., arrive alive at Midway on the planes from the west and are prevented from reaching Honolulu alive by the inspection and spray treatment given the planes at Midway.

All specimens found on the planes at Midway are collected and sent to the entomological museum of the Experiment Station of the Hawaiian Sugar Planters'

Association in Honolulu where they are identified and preserved. They now total thousands of insects.

Similar work is also being done at Canton Island by Richard R. Danner, in order to prevent the introduction of destructive pests from New Caledonia and New Zealand into Hawaii and the U. S. mainland.

Gardening at Midway

Mr. Steadman was the gardener at Midway for Pan American Airways in 1936. He had planted quite a number of ironwood trees, San Francisco grass, and various shrubs, and had started the lawn in front of the hotel, also a vegetable garden. He did very good work considering the difficulties he was up against. Mr. Steadman had fallen down in so many moaning-bird holes that he had developed a chronic limp and always carried a cane. Upon certain exciting occasions this limp would miraculously disappear, and although rather stout he could move with astonishing agility.

Fig. 6. Three-year-old trees on Sand Island. Top—kamani; bottom—ironwoods.

In May or June, 1937, Mr. Steadman's assignment of a year at Midway was ended and he left for the States, and no one was left to care for the gardens and lawns. It was the dry season and everything began to die from lack of water. So the writer, being an amateur gardener and lover of flowers and trees, took over and a Chamorro boy was designated as his assistant. It took all of the boy's time pulling weeds, digging holes for planting and cultivating, and in filling the holes around the corners of buildings where the wind had blown the sand away. Three times that first winter the wind blew the sand out from under, and alongside, all the buildings, especially at the corners where it left holes 3 to 4 feet deep and even undercut the foundations of the buildings so that they rocked from side to side. Many tons of sand were moved in filling these holes. No sooner would grass be planted than another storm would come along and blow the grass and sand away again—it was most discouraging.

It was an unusually dry summer, and the lawns and plants had to be watered daily, one area one day, another area the next day. The volume and pressure of water available was inadequate, and in order to supply the plants with enough water to keep them alive, it took from 12 to 14 hours a day. Only two sprinklers could be used at a time, or one sprinkler and an open hose. The sprinklers had to be changed every half hour, all day long. New plants grown by the Experiment Station, H.S.P.A., were arriving on each plane from Honolulu and had to be potted. This kept me busy from daylight to dark and lasted six months, then another Chamorro boy was added to the gardening department, and things eased up a bit when the winter rains came.

People in the States seem to think that Midway is a South Sea tropical paradise --it is far from it. It is decidedly temperate in climate, cold in the winter and pleasantly warm in the summer. Temperatures range from 50 to 85 degrees F. We never get frost and very rarely a little early morning fog. It rains and blows in the winter time; some of the storms are terrific with gusty winds up to 70 or 80 miles an hour. The summers are almost perfect, warm and calm and not too humid —it is always cool in the shade. We get 50 to 60 inches of rain a year, but the winds and sun dry out the sand to a depth of a foot in a few days. Shallow-rooted plants such as grasses and vegetables suffer from drought in the summer when the

Fig. 7. Pan American Airways' supply ship "Tradewind," and their launch.

rains are not frequent enough. May, June, July, September, October, November, and December are often very dry; sometimes fairly heavy showers occur in August.

Tropical Hawaiian plants grow well here in the summer. In the winter, from January through April, the strong cold winds "burn" the leaves off hibiscus, croton, milo, kamani, vitex and oleander. The leaves and flowers of periwinkles are reduced to one third their normal size, as also are the leaves of Tournefortia and Scaevola. Most of the old leaves drop off, leaving the long bare branches exposed to view. Coconuts are often killed outright by the cold winds; they do well where protected by other trees.

Originally there was no soil on the Island, and consequently it was necessary to make the small amount of soil we had go as far as possible. Only a total of about 30 tons of soil has been available for use in the P.A.A. gardens.

The sand here is coral and shell particles ground up to a fine size by the action of the waves and winds. It is almost pure limestone or calcium carbonate, completely lacking in all plant foods except calcium, and of this there is far too much. In addition, making the growing of plants even more difficult, the only water available in the large quantities needed for lawns and trees is the brackish ground water, which contains just a little too much salt for most plants.

The droppings of millions of birds have added a small amount of phosphate and other minerals in minute quantities to the sand and ground water. There are no deposits of guano here as there are on many South Sea Islands, or as there are on Laysan Island where conditions were favorable for its accumulation over a period of hundreds of years.

Here, what guano is deposited every year is either blown away by winds, or washed away by rains. Except for phosphates, the main elements of plant growth such as nitrogen, iron and potassium are present in such minute quantities that it is amazing that anything can grow at all.

At first it was thought that it would be possible to grow plants here by simply adding large quantities of humus or vegetable matter to the sand. Such an attempt was a complete failure. Apparently the lime sand soon dissolves the humus which is then washed away by rains beyond reach of roots and, consequently, nothing is left to sustain plant life. Most plants failed to grow in a mixture of one-half sand and one-half humus, or in two-thirds sand and one-third humus, even though in both cases small amounts of chemical fertilizers were also added regularly. It was quite a problem. Apparently what was needed is that which is entirely lacking—kaolin or clay. Most soils are composed largely of this material which also contains many of the plant foods, such as iron and potassium.

More than 200 species of plants have been tried out in our "sand pile," in order to determine which will grow in the pure sand, with brackish water, or in sand with a little soil added. It was soon discovered that quite a few plants would grow in the sand even though only a small amount of soil, from Honolulu, was added, providing the soil was very thoroughly and intimately mixed with the sand. However, most of the plants required fresh water, for brackish water soon killed them if given too freely. Small amounts of a complete fertilizer had to be added frequently, every 2 or 3 weeks, in order to obtain satisfactory growth.

A mixture of 1 part soil to 3 or 4 parts of sand was found to be satisfactory for most ornamentals, grass and vegetables. However, about one inch of soil should be added on top of each plot, and thoroughly worked in by spading or hoeing to a depth of 8 to 10 inches every year if the garden is to be kept productive. This can be done at anytime of the year between harvesting and planting.

In order to conserve soil, plots were made for vegetables and flowers, in rows 50 feet long, 3 feet wide and 3 feet apart. Soil was placed on the sand in the rows to a depth of 2 or 3 inches and worked in as deeply as possible. This made a slightly raised bed, with sand walks between the beds. The rows should run north and south, in order for the sunlight to reach both sides of the plants in the plots. Each plot was planted in two rows of vegetables about 6 inches from the edge of the plot. A row of radishes was often planted between rows of slow-growing plants, down the middle of the plot. These were harvested before the other plants had become large enough to shade the radishes.

The following vegetables and flowering plants seem to be well adapted to successful growth under these conditions:

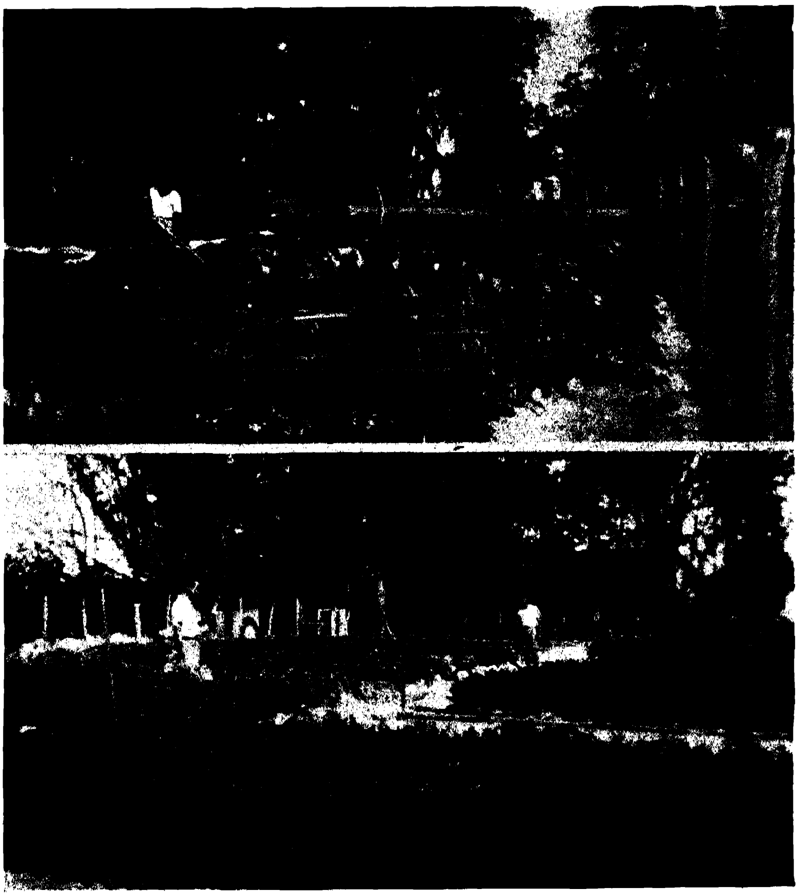


Fig. 8. Pan American Airways' vegetable garden.

Vegetables

Radish (long red)	Chinese cabbage (Wong Bok)
Lettuce (Los Angeles)	Head cabbage
Broccoli	Swiss chard
Beets	Tomato (Marglobe)
Carrots	Eggplant
Turnips	Casaba melon
Sweet potato	Persian melon
Kale (Scotch curled)	Cantaloupe or muskmelon
Kohlrabi	Papaya (if protected from winds)
Rutabaga	

Flowering Plants

Periwinkles	Sunflower
Various-leaved spurge	Nasturtium
Carnation	Gaillardia
Geranium	Sweet alyssum
Chrysanthemum	Stocks
Gladiolus	Pot marigold
Alfalfa	Rose
Tithonia	Begonia
Coxcomb	Poinsettia
French marigold	Oleander
Phlox	

The flowers must be watered with fresh water only, or depend upon rainfall, except gaillardia and periwinkles which may be watered occasionally with brackish ground water. The vegetables should rarely be watered with brackish water. It should be remembered that when brackish water is used there is an accumulation of salt formed, which soon becomes so strong that it will kill anything.

Many kinds of trees and shrubs have been tried, and the following species are the only ones that have been grown successfully in a mixture of sand and soil, one part soil to 3 or 4 parts of sand.

Ironwood	West Indian kou
Kamani	Bengal banyan
Sea grape	Pandanus
Button bush	Coconut (when protected from winds)
Oleander	Palms (date palm type)
Tree heliotrope	

These 11 species may also grow well in the sand without soil or fertilizer, especially the first 5 species, as also do coconut, pandanus, vitex and spider lily.

The following species must have soil mixed in with the sand in order to grow well, and most of them require fresh water.

Tamarix	Sanseveria
Mulberry	*Coprosma baueri*
Banana (if protected from winds)	Acalypha
Baobab	Dieffenbachia
Brassaia	Mock orange
Plumeria	Hibiscus
Flame tree	Bougainvillea
Croton	Poinsettia
Vitex	Panax
Dracaena	Ti

Brassaia, plumeria, croton, vitex, coprosma, panax, and bougainvillea will tolerate small amounts of brackish water. Fresh water should be given to them when available.

Fertilizers:

At first a complete fertilizer was used. This is a mixture of various nitrates and phosphates made by chemical fertilizer companies, and may be called "lawn," "fruit tree," or "vegetable fertilizer." "Gaviota," a mixture made in California, was found to be fairly satisfactory when used in small quantities at frequent intervals.

However, these commercial fertilizers consist mostly of ammonium sulfate and phosphates. If applied too freely it burns the plants badly under Midway conditions. Also some plants apparently showed that they were not getting sufficient iron and potassium. For this reason a new mixture has been tried, and has been found to be more satisfactory. It is:

Nitrate of potash	30%	
Sulfate of ammonia	20%	
Dried blood	10%	(may be omitted)
Sulfate of potash	10%	
Superphosphate	20%	
Iron sulphate	10%	(may be increased to 20%)

Peat humus can be used to advantage on Midway when mixing soil and sand, especially for potted plants such as dracaena, palm, ti, croton, bowstring hemp,

Fig. 9. Pan American Airways' garden showing cantaloupe, cabbage, and turnips.

hibiscus, gladiolus, carnation, zinnia, marigold and other flowering plants. In this case a mixture is made of 1 part soil, 1 to 2 parts sand, and 1 part peat humus. Into 100 pounds of this mixture about 1 pound of the foregoing formula should be thoroughly worked. It should then be wet down and mixed again and allowed to stand for a month or more before using, occasionally working it over again with a spade or hoe.

The peat humus should always be thoroughly soaked in fresh water for at least 24 hours before being used.

Ammonium sulfate should not be used under Midway conditions for just a little too much will kill plants outright.

The only grass that has proved satisfactory at Midway is Bermuda grass. Other species die out in the summer time during warm dry weather. Apparently they cannot stand the combination of so much lime and brackish water, the only water available in large quantities for lawns.

Garden pests:

There are only about 50 species of insects found on Midway. In general they are conspicuous by their absence, with the exception of two species of flies, the house fly and a carrion fly, and ants, particularly *Pheidole megacephala.*

Nearly all of the insects on Midway have been brought here in soil or on growing, potted plants from Honolulu. One bad moth pest, *Prodenia litura,* probably came here from Wake. It is not found in Hawaii.

Our most destructive pest is not an insect at all, but is a bird, the Laysan "finch," introduced many years ago from Laysan Island. This fearless little rascal does more damage to plants on the Island than all other pests combined. It should be outlawed and destroyed at every opportunity.

Mosquitoes were bad when we first arrived here. Many wells and innumerable cans, bottles and other breeding places had to be destroyed before they were controlled. This work has been so successful that many of the new residents on the Island have never even seen nor heard a mosquito since arriving here. The only species present is *Culex quinquefasciatus.* It will be necessary to continue the program of destroying all breeding places if the mosquitoes are to be kept down. All tanks, wells or other water containers must be kept screened, or covered so tightly that no mosquitoes can get into them.

Flies become very numerous and bothersome and a real nuisance in the late summer, especially during July, August, and September. They breed in the dead birds and possibly in bird dung when conditions are favorable. For this reason all dead birds, old eggs and other garbage should be burned or taken far out to sea and dumped on the lee side of the atoll, where it cannot drift back to shore.

Pests that feed on plants are represented by several species of caterpillars, armyworms, cut worms, and loopers. Aphids sometimes breed in large numbers, and scale insects and mealy bugs become numerous enough to be destructive in the summer. Cockroaches also breed rapidly in the summer, especially in and around kitchens.

So far we have been very lucky. We have no scorpions, centipedes or termites on the Island, or if we have they are so rare that they have not been found.

We also have no rats, and it is hoped that great care will be taken, when ships are unloading here, to prevent rats from coming ashore.

The Sea Birds on Midway

When approaching Midway by steamer a strange sight greets the eyes. It appears as if the air over the Island is filled with a vast swarm of giant bees. Upon closer view one soon realizes that there are countless thousands of birds milling around in the air, and their screaming is almost deafening.

In 1902, before the Cable Company arrived at Midway, W. A. Bryan visited the Island. Poachers had already done enormous damage. Thousands of bodies of dead birds lacking tails and wings were thickly strewn over both Sand and Eastern Islands. Apparently they had been ruthlessly slaughtered for their feathers for millinery purposes. Mr. Bryan reported this foul deed to the proper officials in Washington and thus started the campaign to make the leeward islands of the Hawaiian group a bird reservation.

In 1905 a party of poachers was found killing the birds on Lisiansky Island. They were arrested by officers of the U.S. Revenue Cutter *Thetis* and taken to Honolulu. They had killed over 300,000 birds.

Savage Slaughter:

Homer R. Dill and Wm. Alanson Bryan visited Laysan Island from April 24 to June 5, 1911. This is what we find in their *Report of An Expedition to Laysan Island in 1911,* U.S.D.A. Biological Survey Bulletin 42.

In 1909 a party of feather hunters had been on Laysan Island and killed more than 200,000 birds, mostly albatrosses.

Captain W. V. E. Jacobs of the Revenue Cutter *Thetis* arrested 23 poachers and confiscated their booty consisting of the plumage of more than a quarter-million birds.

According to a government official who was in Honolulu at that time these poachers were never punished.

The visitors' first impression was that the poachers had stripped the place of bird life. An area of over 300 acres on each side of the buildings was utterly devoid of birds, and apparently all the goonies in this area had also been killed.

On every side bones were bleaching in the sun showing where the poachers had piled the bodies of the birds after stripping them of wings and feathers. In the old guano shed were the remains of thousands of wings placed there for curing, but never shipped as the marauders were interrupted in their work. In a dry cistern hundreds of live birds had been herded and left to slowly die of starvation in order to reduce the amount of fatty tissue lying next to the skin, and thus making the job of skinning and cleaning the skins easier. Wings had been cut from living birds, and the birds left to slowly bleed to death. Killing clubs, nets and other implements used by the marauders were lying all about. Hundreds of boxes to be used in shipping the bird skins were packed in an old building. It was

evident that they intended to carry on their slaughter as long as the birds lasted. Cages were found in which they had been placing the smaller birds alive.

It is the writer's opinion that at one time goonies were numerous on Wake Island. The wandering albatross has been reported as nesting there. But if they were there, they have since been completely killed off. Three years ago there were 3 black goonies on Wake, this year there were 7 or 8. Apparently they are beginning to move back in again since they are protected by the Pan American personnel on the Island.

Within the past two years, two ships have been wrecked in the leeward islands of the Hawaiian group. One at Kure or Ocean Island, and one at Pearl and Hermes Reef. No one seems to know anything about them. What were these two ships doing in Hawaiian waters, and why were they not reported?

Without doubt other islands, such as Kure, which is rarely visited, have been invaded by poachers, and the birds destroyed for their feathers.

We sincerely hope that in the future it will be possible to keep a closer watch on the uninhabited islands, and if visitors are seen on them and found molesting the bird life, they should be arrested and punished.

Sooty Tern:

Most numerous and noisiest of all the birds on Midway are the sooty terns. The first flock appears some evening in March or April, usually about sundown. Their cries fill the air long before they can be seen. They come in and fly around and around in a great whirlwind-like formation, but do not come down to the ground for a month or more. Sometimes they go away for a few weeks and then return again. All night long they circle and scream over the Island. Early the next morning they again go out to sea for fish. In the evening they are back again. Day after day they repeat this performance, returning a little earlier every afternoon until finally after five or six weeks, they continue to fly over the Island both day and night. Then they begin to light on the ground, at first only for a few moments, and finally after another week they settle down more or less permanently, rising only when disturbed. However, they keep up their incessant screaming long after the egg-laying period has passed.

Fig. 10. The sooty tern.

In the meantime, about two weeks after the first flock has arrived, another one appears. Then for about three months, more and more flocks appear, until by June all the flocks are in and the first to arrive has settled and is incubating its eggs. There must be nearly 600,000 terns on the Island when they are all here. Imagine—over half a million birds on a small Island that you can walk around in an hour and a half! And these are not even half the number of birds that are on Midway in May and June.

What kind of a bird is this noisy, powerful flyer, and what does he eat? The sooty tern is a small, graceful, perfectly streamlined, black-and-white bird, with partly webbed feet and two long tail feathers. The breast and neck are snow-white, and the back and top of the head are sooty black. The beak is long, straight and sharply pointed. It is about the size of a dove.

It lays a very large egg (for its size) on the bare sand, sometimes in a slight depression, and the egg hatches in about a month. Both mother and father bird take turns setting on the egg, changing off about once a week. While one bird sets on the egg the other is out fishing, sometimes far at sea. Here in the open sea it catches small fish and squid or cuttle fish; it also catches small minnows inside the lagoon.

The newly hatched bird is covered by one or the other of the parents for about a week; from then on, one of the old birds stands guard near by until it is nearly full-grown. The old birds feed the young one by regurgitating the partially digested fish they have obtained at sea. This species of tern never feeds the young whole fish, but always partly digested material. In about three months the young bird is full-grown and begins to fly down to the edge of the beach or to sea with its parents. At this time it is a speckled, dark gray bird that does not look at all like the adults. A week or two later they all disappear out to sea again, and no one knows where they go. Very likely they stay at sea all the time they are gone, from August to April, and rest now and then on the water.

The first five or six weeks of a young tern's life is fraught with danger. Frigate birds swoop down, grab them without lighting and gobble them down. This doesn't seem to bother the old terns very much for they do nothing about it. One frigate bird was observed to eat eight young terns in one day. But just let a human being try to walk through a colony of nesting terns. What a rumpus they make, and how they apparently swear at you. They are very brave little fellows, and stand right there by their egg or young, facing you without moving, and telling you in no uncertain terms just what they think. Others fly around your head and occasionally peck you with their needle-pointed beaks, sometimes drawing blood. Usually it is just bluff and they don't touch you. Imagine a person standing up and fighting an elephant. And yet we must seem many times larger in proportion, to that valiant sassy little tern that stands up about six inches high on his toes. We hereby elect him the bravest of the brave.

The Fairy Tern:

Less numerous, but one of the favorites on the Island are the beautiful snow-white fairy terns or love birds, with their bright, shiny, jet-black, shoe-button eyes and blue-black pointed beaks. They are a little smaller than the sooty tern, but

Fig. 11. The fairy tern.

friendlier and much quieter. They are curious and often follow you, circling around over your head, chattering in a low deep voice. If you stop and hold out your finger at a level with the top of your head, and stand quietly they often alight on your finger, or on your head.

Instead of laying eggs on the ground they place them on a bare branch, or in the crotch between two or three twigs. They make no attempt at building any kind of a nest at all. It is amazing that the egg can stay in such a position, but it does, and rarely falls off even during high winds.

It is said that when the young hatch, the feet come through the shell first and fasten on to the branch! (This may be taken with a grain of salt.) However they do it, it must be very tricky. They do hold on so tightly that you almost have to pull them in two to get them off that limb.

At first the old birds feed the young by regurgitation, but very soon they are bringing small top minnows in to the babies which they cram down their throats. Adults often bring in two, three, and even four minnows at a time, held crosswise in the beak. Now, how do they catch that second and third fish without losing the first and second one?

Other Terns:

The Hawaiian tern is not so friendly as our little "fairy." It builds a nest in the ironwood trees, or in the Scaevola bushes, where it is hard to find. It is a very dark gray, almost black, bird with a light gray or almost white "bald" spot on top of the head. It makes a very peculiar noise at night.

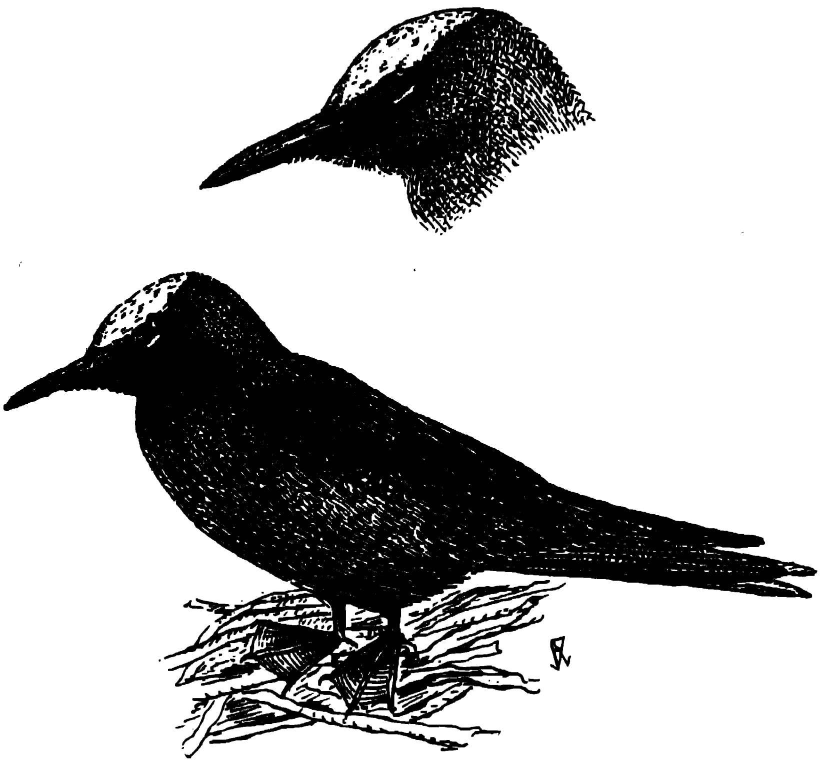


Fig. 12. The Hawaiian tern.

The grayback tern is larger than any of the others, and quite rare here.

This makes a total of four species of terns on the Island. Their numbers are about as follows:

Sooty tern	600,000
Fairy tern	3,000
Hawaiian tern	2,000
Grayback tern	500

Moaning Birds:

Next in number of individuals, and larger in size, are the moaning birds, of which there are several species.

Most numerous are the Bonin petrels, a bird about the size of a pigeon. A conservative estimate of the number of this species on the Island is 500,000. The Bonin petrel is known as the "small moaning bird" on Midway. It has a white breast but otherwise is a dull gray. The beak is turned downwards at the tip into a sharp hook.

This species is not nearly as noisy as his big brother the wedge-tailed shearwater. Both of these species, and many others, are known as Mother Carey's chickens by sailors. In fact the Bonin petrel makes only a small meowing sound, or a kind of a growl, like a kitten does when you try to take a piece of liver away from it.

Sometimes while mating they have a high shrill cry that is very disturbing. Although they are sometimes seen at sea in the daytime, they are really nocturnal, and do not become active until after sunset. At that time they come out of their burrows in the sand, and actually fill the sky with their great numbers, appearing from a distance like a great swarm of bees covering the entire Island. Over a thousand of these birds were counted on one-half acre near the Pan American Airways' Inn.

Bonin petrels are wonderful diggers. They usually get their head or shoulder up against a plant stem in order to get a leverage for digging, and then they make the sand fly. The burrow is usually about six to ten inches below ground, and three to four feet long. They toss the sand out of his hole to a distance from eight to ten feet, using first one foot and then the other. A rabbit couldn't dig a hole any faster than they do.

They begin to lay eggs in December or January, in a nest lined with leaves at the bottom end of the burrow. The egg is almost as large as a hen's egg. They return to the Island early in September and leave in June, so that there are only two months—July and August—when they cannot be found. A small flock may return in August.

Since Bonin petrels dig holes all over the Island, even in low places where the water level is only a foot to eighteen inches below the surface of the sand, many are drowned during heavy rains. After a heavy rain, of three to six inches, the water rises and floods the lower areas of the Island. However, this does not prevent the old bird from returning again and again to dig in the same old place.

The Bulwer's petrel, all gray in color, is a small moaning bird that is rarely seen on Midway. It has a characteristic cry of "Hoomph, Hoomph, Hoomph," in a deep tone.

Wedge-Tailed Shearwater:

Any person taking a walk around Midway in the evening when it begins to get dark, during March or April, is apt to have a most hair-raising experience. Suddenly out of the dark will rise the most blood-curdling howls, yowls, moans and groans. Not only that, but it sounds as if there must be a dozen tomcats tearing each other to pieces, from the wild cat-like shrieks that penetrate the ear, then some woman begins to groan and gasp and moan, as though about to die in the greatest

Fig. 13. Moaning birds: left, head of Bonin petrel; right, head of the wedge-tailed shearwater.

of pain. All of these various ghoulish noises are so heart rending, so horrible, that one must indeed be brave to investigate them. What a horrible experience it must have been for those first sailors who were shipwrecked here many years ago. Certainly they huddled around their fire trembling and shaking when they first heard these wild cries.

However, if you are brave enough to approach the source of these sounds with a flashlight, or even on a bright moonlight night, you will find that all this terrible racket is made by only two or three pairs of birds, only half again as large as the Bonin petrel, and very similar to it.

They are the "big moaning bird" or wedge-tailed shearwater, the big brother of the "small moaning bird."

There is only one bird that can make a more terrible noise, and that is the "devilbird" of Ceylon and India, a small owl that has an even greater volume and repertoire of terrible cries. There are not many animals that can even begin to compete with either of these two birds.

These cries are the love song of the big moaning bird! Its throat swells out like a small balloon as it passionately sings its love song, which can only be appreciated by another moaning bird. They keep up this din for several weeks, then settle down to the business of digging holes, setting on the eggs, and feeding the young.

They dig a much larger hole than the other "moaners"; it is also deeper and longer. Often their burrow is excavated beneath that of a Bonin petrel, and thus may be down in the ground two to three feet. It is about four or five feet in length and eight to ten inches in diameter. Anyone walking across the Island is bound to fall into these burrows many times, and get shoes and socks full of sand as it caves in around one's feet. For this reason the moaning birds are heartily and fluently cursed by the inhabitants of Midway. You suddenly break through sand, that looks solid, and end up with a jolt, which is very funny when you see the other fellow do it.

The gardener at Midway had made a very nice little garden when the moaning birds were away. After the beets, radishes, turnips, lettuce, carrots, etc., had got a good start, the birds moved in. One night he went out to see how the vegetables were doing. The carrots, beets, turnips, radishes, and lettuce were flying in every direction. The moaning birds were home again, and excavating work was fully under way. There were 1,500 moaning birds at work in that little three-fourth-acre plot.

The wedge-tailed shearwater apparently eats mostly squid, but does eat some small fish.

In August another smaller flock of big moaning birds returns to the Island. The egg is almost as large as a hen's egg. One of the amazing things about nearly all sea birds is that they lay such large eggs in proportion to the size of the bird.

The Bosun Birds:

The bosun bird or red-tailed tropic bird is a beautiful white bird with a pink, pearly iridescent or opalescent sheen to the feathers. The beak is a bright red or orange, as are the two very long, thin tail feathers; the feet are black, and

Fig. 14. **The bosun bird or red-tailed tropic bird.**

webbed. They nest on the ground in the Scaevola bushes around the P.A.A. hotel. They are found on the Island from May through December, and are away on their winter vacation, probably "down south," from January through April.

These are the birds that fly backwards, just for the fun of it! No, not all the time. During the warm weather in May, June, July and August, at 11:00 a.m., they leave the nest and get up into the air and do a kind of aerial acrobatic dance, accompanied by a great deal of loud squawking in a very raucous voice.

They mill around and around in the air, then go into a gliding dive, pull up into a stall and then fly up and backwards, loudly squawking at the same time. When they do this the two long tail feathers are brought down under the stomach and point forward; we doubt if they help any in flight, for they may switch them to one side or the other without any effect on the direction of flight. This dance always goes on from 11:00 a.m. until 2 or 3:00 p.m. every warm day. They can even fly backwards on a calm day, when there is no wind to blow them backwards.

The young when full-grown have a gray beak and are mottled black and white, but do not have the two long tail feathers. One day we were teasing a young bosun bird that was about 10 inches long. Suddenly it seemed as if it were turning itself inside out. It was really throwing up a partly digested needle fish (small gar) that must have been wound up like a clock spring inside the little bird's crop. The fish was twice as long as the bird!

The Frigate Bird or Man-of-War Bird:

By far the best flyer of all the sea birds is the frigate bird. Hour after hour, day after day he hovers on tireless, almost motionless wings, high in the air over the Island, waiting for the boobies and bosun birds to return from sea. Whenever he sees one of these birds returning, heavily laden with a crop full of fish, down he swoops on it at a terrific speed, and gives chase until it disgorges its meal. He then swiftly swoops again and grabs the disgorged fish, before it hits the ground or the sea, and eats it himself. That is one way to get a hot meal! The booby dodges, and croaks its objection to such treatment, but invariably must eventually "give up" to its enemy. The bosun bird also dodges and squawks in protest, but also must finally donate its share to this robber of the skies.

The frigate bird is the eagle or hawk of the sea. It is a large black bird with two long tail feathers. The beak is very long, hooked, and powerful. Adult males are an ugly yellowish brown on the under side, and during the mating season they can puff out their chins into ugly red pouches as large as a child's head. In the female the neck and breast are white.

Although frigates prefer to obtain their food "secondhand" they can also fish very well for themselves, snatching surface-swimming fish directly out of the water while on the wing. Frigate birds usually fly with the two long tail feathers slightly spread, or forked. They fly by soaring instead of flapping the wings like most birds do—they rarely flap their wings. They are experts at finding and taking advantage of rising warm air or updrafts, over the Island. They can often be seen apparently motionless, or slowly circling at a height of about 1,000 feet over the Island, where they are waiting and watching for bosun birds or boobies to return from sea with full crops, or they may be "spotting" some young tern. A frigate will swoop down, without touching the ground, pick up a young tern in its beak, fly up in the air to a height of over a hundred feet, and then toss its victim up into the air and catch and swallow it in one gulp! These cannibals may devour 8 or 10 terns a day.

Frigate birds are the only birds leaving or arriving at Midway in mass formation. This arrival or departure is rarely seen, possibly because they leave either very early in the morning or at night.

On December 29, 1938, a large formation of frigates appeared above Midway. They were coming from the southeast and flying directly into the wind which came from the northwest. Kure or Ocean Island is the only island to the northwest of Midway—they must have been headed for it. They formed a line 3 to 5 abreast for as far as the eye could see in both directions. Five hundred birds were counted, but some had already passed, and they were still coming when the observation was discontinued. They flew into the wind at a height of about 2,000 feet without any apparent movement of the wings or feathers.

We have never seen them attack a gooney, not even the young goonies.

Fig. 15. The frigate bird or man-of-war bird with young.

In spite of its great size—wing spread of 6 to 7 feet—the frigate is a comparatively light bird, weighing only from 5 to 6 pounds.

We often know when the frigates are going to leave Midway because early in the morning when they are preparing to leave, they all form together in a loose formation and circle around over the Islands. Nevertheless, the actual departure or arrival is rarely observed.

The frigate birds build very crude nests of sticks in the Scaevola bushes. The young are very ugly "critters," being more or less dirty, mottled rusty-brown in color. When approached they stare at one with a malevolent insulting air, and viciously strike with their long beaks.

The Boobies or Gannets:

There are 3 species of boobies or gannets at Midway—the red-footed booby, the blue-faced booby, and the brown booby. They are all smaller than the goonies, but larger than the bosun birds. They can be distinguished from all other sea birds by their exceptionally short legs. They always look like they are standing in a hole, or have had their legs sawed off! It just doesn't seem right for a bird to be built so close to the ground.

Boobies can maintain their balance on the wildest of rolling, pitching buoys, no doubt due to their low center of gravity. They have a perfectly streamlined body and are real amphibians, that is, they can swim as well as fly, and fly as well as swim! In addition they are one of the most perfect high divers in the world; pelicans are clumsy affairs in comparison. (There are no pelicans on Midway.)

The booby flies along at a height of 50 to 100 feet above the surface of the sea looking for fish. It flaps its wings more than does a gooney. When it spots a school of fish, near the surface, it pulls up into the wind, lowers its head, looks from side to side, chooses the fish it wants, folds up its wings and "power dives" on the victim. It almost always gets the poor fish. The booby swims so fast under the water that when it comes up out of the water it emerges at an angle of 45 degrees

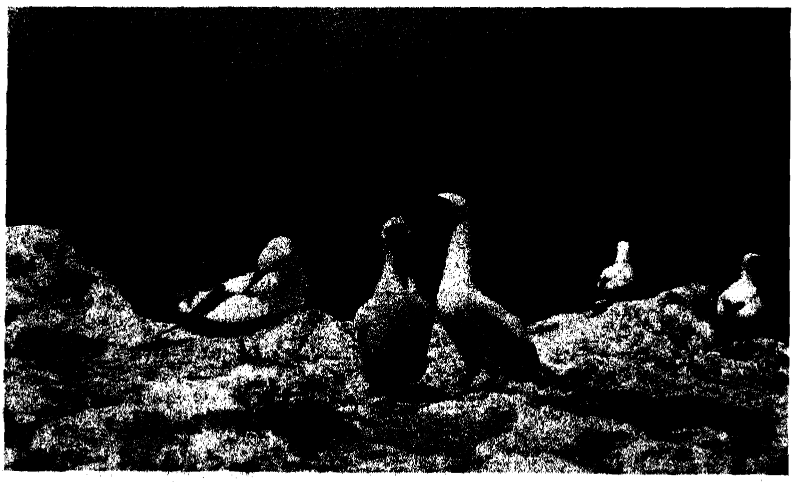


Fig. 16. The boobies or gannets.

—on the wing—and is in full flight. It does not have to run along on the water like a gooney does.

Boobies also build crude nests of sticks and leaves in the Scaevola bushes. The young are funny, ugly, fuzzy, yellow rascals which should be approached with care, keeping well to the windward. They may turn loose a shower of filth on you, which brings to light an amazing thing. Although the air over the Island may be filled with countless thousands of flying birds, such as goonies, terns, and moaning birds all of which excrete while on the wing, they rarely make a "direct hit" on the poor lowly humans below. How these marvelous fliers must look down on those poor creatures that are earth-bound!

The adult blue-faced booby is black and white, with a blue-gray, yellow, or more often greenish yellow pointed beak; skin of face is blue-black, very dark. The feet are olive-drab or bluish gray in color.

The red-footed booby is also black and white; its bill is light blue with brown tip and red base, and the naked skin on its face is blue. Its feet are red and smaller than the above species.

The brown booby is the most common at Midway. It appears to be all black, but may have a gray or white stomach. Its bill is yellow, or bluish white, and its feet are pale yellow. This species is often seen perched on the railings of the docks at Midway, or upon pilings.

Boobies can dive to a depth of 90 feet! They have been caught in nets at this depth.

White Gooney or Laysan Albatross:

Best loved, most amusing, and always spectacular are the white goonies on Midway. This beautiful bird—large as a goose, with snow-white breast, neck, and stomach, delicate gray shading around the eyes, "Charlie Chaplin" gray feet, dark gray back, intelligent, bright shiny black eyes, and long powerful curved yellow beak tipped with gray, and with dark gray or nearly black wings—is the most popular bird on the Island.

By unanimous vote of all persons on the Island this is the king of birds. Not only is he a king, but also a clown. He is not afraid of anything, not even the great caterpillar tractors, autos, or people. Always polite, he rises and bows to you when you pass near him. True he may viciously snap his beak at you, but that is only a warning, and don't go too close, or that powerful beak will take off a finger, or cut a long gash in your arm or leg. You don't believe me? Just try it! With that organ of destruction he tears large, live squid and cuttle fish to pieces, and swallows hunks as large as your fist.

Why are these big birds so tame, so friendly and brave? Simply because for thousands of years there has been no animal or bird on the Island that could harm them. Some, but not all, are extra friendly. These individuals may be slowly, closely approached and petted, or scratched on the side of the cheek, or the back of the neck. They love it, but be careful; don't frighten them by any quick movement, or you shall pay dearly for it.

In the air the white gooney is one of the most graceful of birds. How easily they glide back and forth over the waves or over the sand dunes in the wildest of

storms without apparently moving a wing. But what a change occurs when they land. On land they are clumsy and waddle along ducking their heads and leaning from side to side with every step, their big webbed feet going plop, plop, plop. Like a plane they need a long runway into the wind in order to take off. Only when

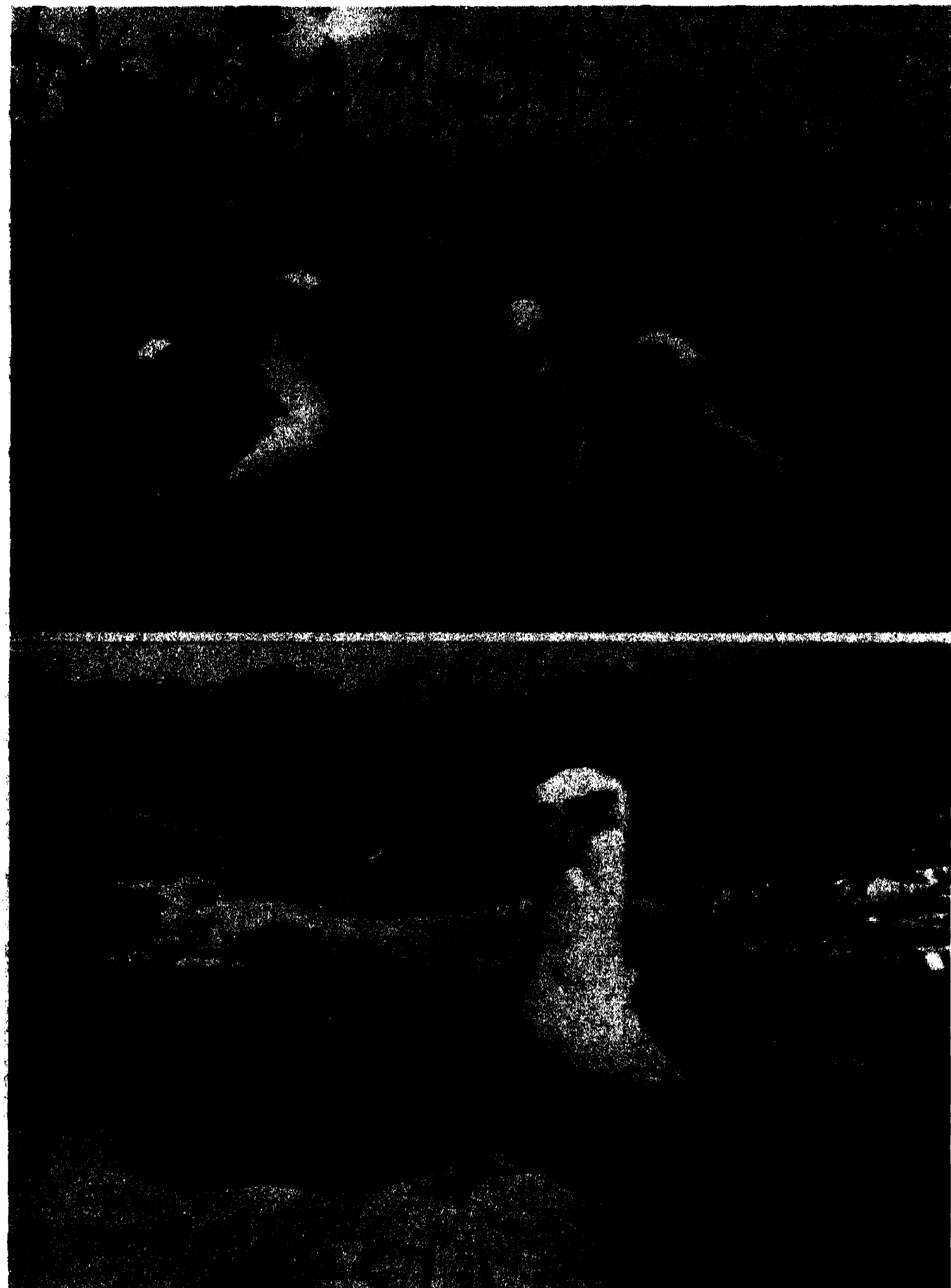


Fig. 17. Laysan albatrosses or white goonies: above, adults; below, mother and young.

there is a strong wind blowing can they take off easily with a short run of from 15 to 20 feet. In calm weather they must run for a hundred yards or more and get up plenty of speed, their feet throwing up a shower of sand before they can really get under way. But once in the air they are most graceful and the master of this element. Their great wings have a spread of from 6 to 8 feet, and they are sometimes mistaken for a clipper plane coming in over the horizon. They rarely flap their wings like other birds, and then only to assist in getting up speed for the take-off, or occasionally on very calm days when there are no air currents to aid them.

When the goonies first return to the Island they are big and fat and clumsy. For 3 months they have been out at sea and have been accustomed to landing on water. Their first attempts at landing on a hard surface are comical. One comes in at full speed, then down go his flaps (feet), the tail drops, and as he reaches "stalling speed" his wings shake and quiver. He then hits, and hits hard. He has forgotten to take the brakes off! On water he simply elevates his toes and skids along. On land this doesn't work. He forgets to run and over he goes on his breast, with face and beak scooping up sand as he skids along on his stomach or even does a somersault. Then up he gets, looks around to see if anyone has seen him make that crash landing, shakes the sand out of his mouth, snaps his beak, raises his head skyward and gives himself the Bronx cheer! Then over he goes to some of his friends, bows a couple of times and sits down to rest and wait for the others to come in.

The males usually return first, and sit around waiting for the females to arrive.

Fig. 18. Laysan albatross or white gooney on nest.

By November 15 nearly all of the males have returned, and a few of the females.

After mating is over the dancing begins. The gooney dance has nothing to do with mating. Although an occasional pair may be seen dancing during the mating season, it really doesn't get started until after the mating season is over, and then it lasts all through the nesting season, slacking off when the young are nearly full grown. At this time it keeps the old birds constantly working to feed their young and they do not have time for the lighter things of life.

The goonies are very polite birds, and almost invariably bow to each other when they meet. This usually starts the dance. First they bow several times, then they "fence" with their beaks, rapidly knocking them sidewise against each other's, then they very rapidly snap their beaks, making a popping noise like the rattling of African bones, or a machine gun, or the roll of a drum. They then shake their heads rapidly from side to side at the same time giving a cry like the whinnying of a colt, a kind of a high shrill whistle. It is a wonder they do not addle their brains with this rapid shaking of their heads. The next motion is to partially spread one wing, scratch themselves under the "arm pit" with the tip of their beak like a dog biting fleas, and then stand on tiptoes with head and beak stretched skyward as far as they can reach. In this attitude they give the well-known Bronx cheer or raspberry. Sometimes this sounds like a sick cow mooing, at other times like a calf bawling. They again proceed to bow and nod rapidly in unison, and repeat the entire procedure, but with infinite minor variations. For this reason one is invariably compelled to stop and watch this fascinating dance. It is always good for a long laugh.

Fig. 19. Laysan albratrosses or white goonies in typical dance pose.

Usually a pair dance together, then a third edges in and all three dance together. This will sometimes cause a fight, the intruder often being attacked by one of the two original dancers. During the mating season there are many fights between males desiring to court the same female.

Sometimes these fights are very vicious affrays, at other times they last only a few moments, with one or the other running away with his swift comical waddle, and wings spread for balancing. When a real vicious fight is under way they strike at each other's eyes, mouth, tail and wings, trying to obtain a painful hold, which they keep with a bulldog tenacity. Sometimes one is able to insert the upper portion of his long powerful beak deep down the other's throat. The needle-pointed, downward-hooked beak slits the throat, sometimes cutting the jugular vein and causing death.

During all this they are madly screaming at each other in a high shrill squeal. If not killed, the loser runs off squealing with wings spread. The winner raises his head and gives the loser a loud derisive squawk. Very few birds are badly enough hurt during these fights to cause death; however, they may be bloody affairs, so that the beak, face and neck will be splotched with blood. When the loser runs away, he is usually pursued a few yards by the winner.

Occasionally, after most of the mating is over, one may see 7 or even 8 goonies dancing together. Usually however, not more than 2 or 3 are in a group. This dancing continues throughout the year from December to July.

All species of goonies do a somewhat similar dance, but each has its own routine.

After mating, the serious matter of nesting is considered by these birds which seem almost human, although after mating they often go to sea again for a short

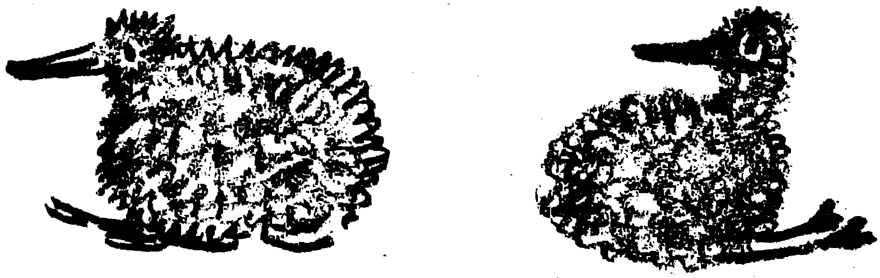


Fig. 20. "What's doing?"

Fig. 21. Attempted "take off."

time (about two weeks) before starting nest building and egg laying. A pair will wander off together looking for a place to nest. At this time the sounds they make are quite distinct from any made previously. It is evident that they are seriously discussing the important matter of locating and building the new nest.

The male calls the female over to the place he likes with a shrill trilling whistle, his body shaking with effort. Then he ducks his head several times, picks up a few pieces of grass or leaves in his beak and drops them around him in a circle. Then he says "ah! ah! ah!" in a wheedling tone of voice, as if to say "mamma, here is a good place!" So mamma comes over near papa and also begins to indiscriminately scatter grass and leaves around the countryside, in a hit or miss fashion. Then she decides that that isn't such a good place, and moves over a foot or two, and they both pull up some more grass and scatter it around. At the same time she will scoop out a shallow bowl-shaped depression with her feet, for which purpose she has a handy set of sharp claws on the ends of her toes beyond the webbed portion of her feet. You can receive nasty scratches from these claws if you are careless in handling the birds. Nest building begins in earnest just a day or two before the egg is to be laid. However, we have seen a female come in, land, go immediately to what she feels is the proper place, scoop out a hollow, line it with leaves and trash, build up the edge into a crater with sand, and lay the egg, all in the space of only a few hours.

The male may or may not be present. Usually he waits around for the female to come home. Then he assists her in building the nest. Part of the time he pulls weeds and drops them where the female can use them, at other times he drops the grass and weeds any place, or even takes them away from the nest and drops them farther away out of reach of the female. In this way he may be more of a hindrance than a help in nest building. Often they build more than one nest before permanently settling down in the last one made.

Soon after the egg is laid the male gently pushes the female off the nest and in turn sits on the egg for 2 or 3 weeks. In the meantime the female goes out to sea fishing. They change off on the egg about every 18 days. During this time, while sitting on the egg they neither eat nor drink.

There is a great deal of difference in the characters of different birds, fully as much difference as there is between individual humans. Some are calm and collected, being quite tame and friendly. These may be approached quietly, and petted or scratched on the back of neck or top of the head or cheek, without their becoming

Fig. 22. "Take off."

excited and biting one. Others are nervous and temperamental, and will viciously snap long before one gets near them. Some build a nice, big, high crater for a nest. Others build no nest at all, but lay their egg in only a slight depression in the sand, without bothering to line it with leaves and sticks. One of a pair will sit on the nest picking up one beak full (½ teaspoonful) of sand after another (all day long) and piling it up around the edge of the nest, at the same time carefully patting it down firmly with the side of the beak. Thus a very fine high nest, a perfect miniature crater is built up. Then the mate will come in, take its turn, and sit there and do nothing but sleep most of its 18 days on the nest. As a result the nest slowly goes to pieces, being blown away by high winds, or washed away by heavy rains.

The egg is very large, being 8 to 9 inches around the shortest diameter, 10 or 11 inches around the long way. It is oval in shape, smaller at one end, and weighs 8 to 9 ounces! That is a rather large egg for a bird that weighs only 6 or 7 pounds.

After the egg is dropped, the bird reaches down and touches it all over with the tip of her beak. Then she talks to it saying "ah, ah, ah," then gives a loud squawk and covers it with her body. Sometimes within an hour or two the male gently pushes her off the egg and takes her place. This change always takes place only after considerable "talking it over." The one on the egg always hates to leave it. Sometimes the male does not appear for a day or two to relieve the female, but usually the change occurs the same day the egg is laid.

The first white gooney appears about November 1. It comes in and rests for a day or two, but soon gets tired of sitting around by itself, and goes out to sea again. From November 7 to 10 a few more appear and wait for others to come in. The first egg is laid about November 20 and by this time about 60 per cent of the goonies have returned to Midway. By December 5 most of the eggs have been laid, and on January 25 the first egg may hatch. By February 10 almost all the eggs have hatched, with only about a 5 per cent failure.

Sometimes a bird sitting on the egg gets tired of waiting for the mate to come in and relieve it so it leaves the egg. The egg may be left exposed for several days. Then one or the other returns and sits on it. Some eggs have been left uncovered for 4 or 5 days, but hatched just the same. Occasionally during the last month before the egg hatches one mate fails to show up to take the other's place. In such a case the bird on the nest may remain on the egg for as long as 30 days or until

Fig. 23. "Three-point landing."

it hatches. That is a long time to go without food or water, except for the few drops of rain water that may fall into the narrow beak. It takes 9 weeks for the egg to hatch—a long incubation. Most birds' eggs hatch in 3 weeks.

The adult bird covers the young newly hatched gooney for another week or 10 days before leaving it. By this time it is so big the old bird has difficulty covering it. From then on, for 5 or 6 months, the old birds feed the young one by regurgitation. This is a somewhat painful process for the adults.

Nearly all the sea birds drink sea water. In hot weather they can be seen flying low over the ocean dipping up water in their beaks. This is especially noticeable with the terns, which form a constant stream flying from the nesting grounds, out to sea, near shore, where they dip up a few drinks and then immediately return to the nest.

When the older goonies return to feed the young, they plainly recognize their own babies, and the baby distinctly recognizes mamma or papa. All young goonies, and all old birds look alike, at least to the human eye. However, the babies start to cry "peep-peep-peep" and beg for food the minute their own parent appears on the scene. After feeding the young, the old bird rests for a short time, a few hours or maybe over night, then again goes out to sea fishing.

When the babies are 2 or 3 months old they begin to wander from the nest and pick fights with each other. If one of the parents returns and finds the nest empty, it looks around until it finds its own young one and then proceeds to give it a good beating, by pecking at its neck and back. The young one bows its head, hiding its face and beak in the breast feathers. The little fellow seems to know he had no business being away from the nest, so as soon as the old bird stops trouncing him, he runs home. Then, and then only will the parent feed him. If he lets out another peep before reaching the nest, he receives another beating.

Sometimes a young one that is starving will beg food from an old bird that is not its parent. He always gets a terrific beating, but never any food. This is especially true later on, in July and August, when the young are nearly full-grown, and some of the old birds fail to return to feed their young. About 5 per cent of the young birds die from starvation at this time. Between the ages of 1 month to 6 months about 10 per cent of the young die from disease, starvation, or by drowning in low-lying areas during floods.

When first hatched, and for 6 or 7 months the young is covered only with a layer of fine fuzz, dark gray in color. This fuzz is lost and slowly replaced by

Fig. 24. "Two-point landing"

the regular adult plumage during the last two months they are on the Island. Later they have all adult plumage except for the ring of dark gray fuzz around the neck which gives them a very comical look.

When the old goonies think it is time to leave, they go. The young are left to learn to fly by themselves. They learn by trial and error, mostly error at first. When they are about 7 months old (in July) we have occasional summer showers. Every time it begins to rain it blows, and all the little goonies stand up, face into the wind, spread their wings and violently flap them up and down. This develops their wing muscles. It looks like a lot of umbrellas going up. By this time the wing feathers are more or less fully developed. As the muscles get stronger the young birds hop up and down in the same place, then take a few steps forward into the wind. If a violent gust of wind hits them they may even leave the ground for a few feet. They are often blown over backwards, and land in a heap, much to their chagrin. Sometimes they go into a nose dive, and hit with an awful thump, but they are tough and can "take it." They get up squawking and try all over again—it is very laughable. Pretty soon they learn to run quite fast with wings widely spread and flapping with all their might. They reach an altitude of 8 or 10 feet, look down, get scared, fold their wings, and down they come and hit hard. It may knock the wind out of them, but they soon try again. It takes them about a month to learn to fly—then away they go.

During the latter part of July and the first two weeks in August very few old birds are seen on the Island. They are too busy feeding the young ones to put in their time loafing on land. They come in, feed the young and go right out to sea again. That is why some people think the old birds leave several weeks before the young birds have become full-grown. However, by August 15 all the old goonies have left, and most of the young ones. Only a few starved, sick ones are left on the beach where they have wandered. These usually die. Many drown in the lagoon and are eaten by sharks. We have seen an 18-foot shark gobbling up these weak young birds. They cannot take off from the water. Baby goonies

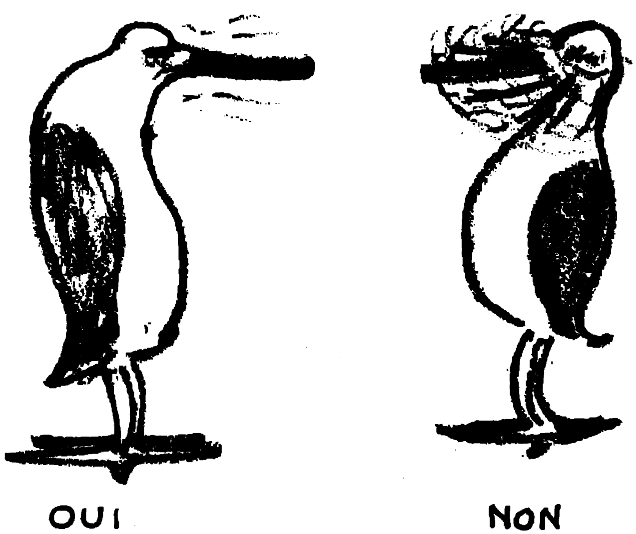


Fig. 25. "Dancing."

are in some respects very much like human babies. As soon as they can shuffle around on their elbows they pick up everything they can find, in their mouths and chew on it. They appear very intelligent with their bright, shiny, black eyes, and "cocky" ways. Some of them are very shy, and hide their heads as if in shame when approached. Others sit up high so they can see better and snap at you—when you get too close. Still others will gently nibble at your fingers. When young they cannot bite very hard. A few of the young ones can be taught to eat out of your hand, and they will gobble up anything offered them. Best of all they like sardines and canned salmon, but they also gulp down pieces of steak, ham or even a whole bun. The bun will stick in their throat and they have to pump it down.

That old goonies eat mostly squid or cuttle fish is proved by what they throw up. This is the remains of squid and cuttle fish, occasionally parts of flying fish or mullet, and some stones. These stones are very light in weight, being a pale, gray pumice filled with thousands of little air bubbles. We have not yet been able to determine where they get these crop or gizzard stones, possibly some place near Japan.

A California zoo obtained permission to capture and import into San Francisco 4 live goonies. Four full-grown, young white goonies were caged, and sent in by clipper. One died on the way, and one died soon after arrival. Food had to be forced down their throats, and after a few months the remaining two died. It is said that birds in this family have never been kept alive in captivity. Very likely, when the time comes for them to go on their annual vacation, they must do so or perish.

No young ones ever stay on the Island until the old ones return again. All have left Midway or died by August 20. From August 20 to October 12 or 20, no goonies are seen at Midway, not even at sea!

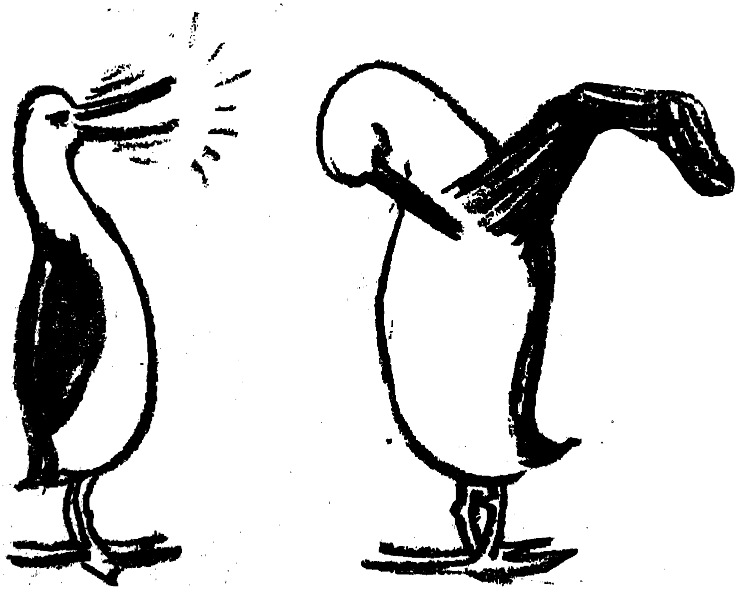


Fig. 26. "Dancing."

In July, 1937, 90 young birds were banded. None ever returned to the Island. One was taken aboard a Japanese fishing boat 300 miles from Japan on December 12, 1937, about 2,000 miles northwest of Midway.

Goonies possibly live to be from 15 to 20 years old. There must be about 20,000 white goonies at Midway. There are over 2,000 on the P.A.A. compound by actual count.

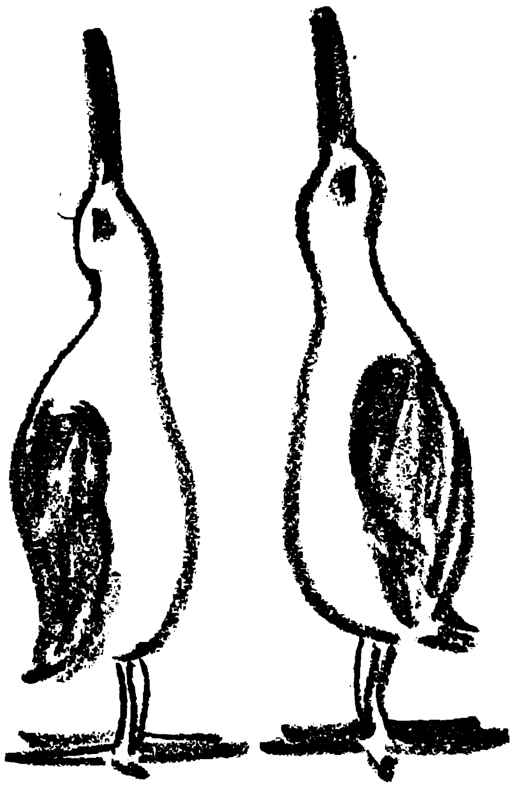


Fig. 27. "Dancing."

The Black Gooney:

The black gooney or black-footed albatross is the other species of gooney found on Midway. It is nearly all black, or dark gray with a brownish sheen to the feathers, and with black beak and black feet, and white under the tail.

The black goonies return about two weeks ahead of the white ones, usually between October 15 and October 25, and they leave earlier, all having left the Island by August 1. Both species are about the same size, lay the same size eggs, and feed the young in the same manner. However, the black goonies prefer to nest around the edge of the Island on the sand of the beach, at some distance from the water and beyond the reach of high tide. The white goonies prefer to nest inland.

The black goonies dig a deeper hole in which to nest. Often during violent sand storms the young ones become completely covered up, or have just their heads and necks sticking out of the sand. They die if they are not dug out. The parents apparently cannot, or do not dig them out when thus buried. There are more black

goonies on the Island than white ones—possibly some 30,000 individuals. They seem to be hardier than the whites, but a white will outfight a black one nearly every time.

The black goonies have a different kind of a voice than the whites, it being deeper and coarser. At times they sound much like the honking of geese or the quacking of ducks.

They dance more rapidly than the whites, and when a white and black try to dance together they soon get out of tune or rhythm, so one or the other soon walks away in disgust.

They very rarely inter-breed, as a matter of fact we have seen only one bird, a light gray in color with partly white breast and neck, that may have been a hybrid.

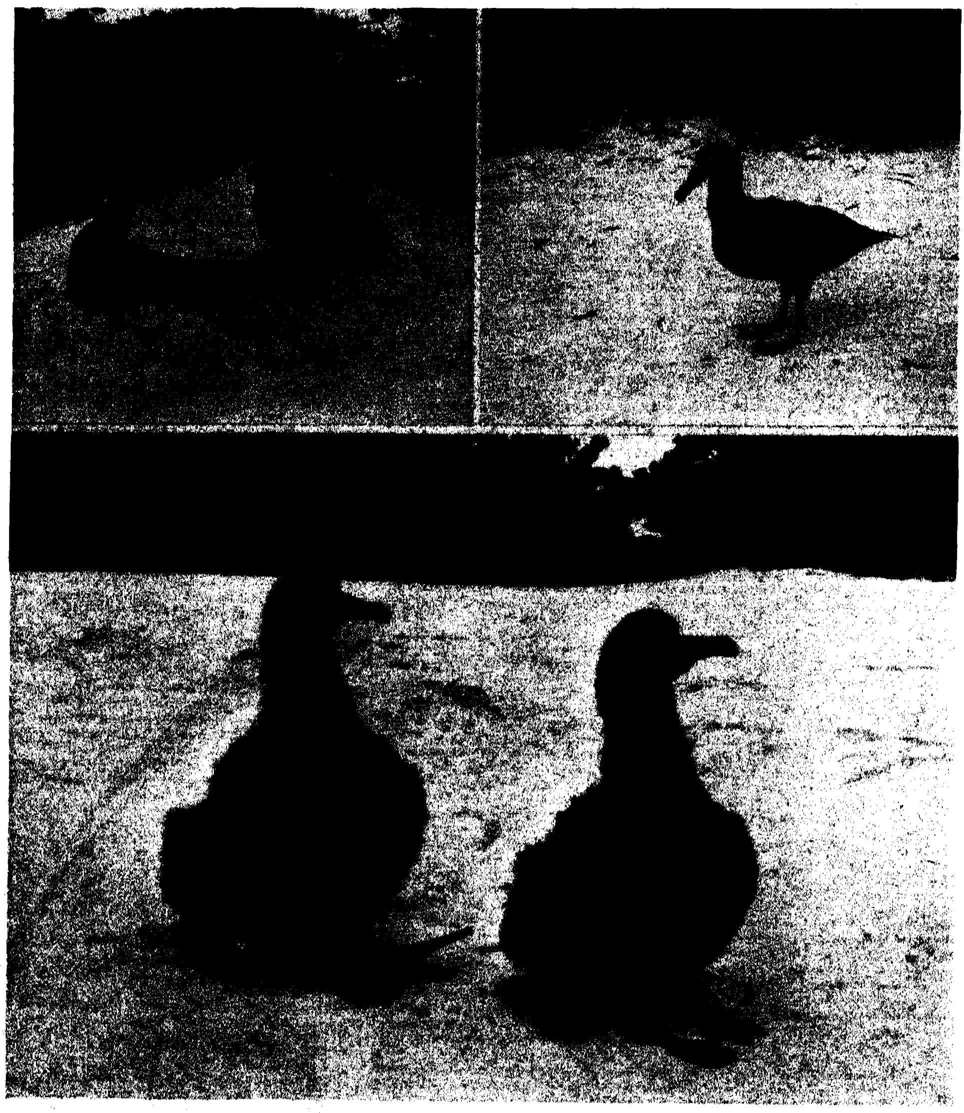


Fig. 28. Black-footed albatrosses or black goonies, adults and young.

When walking, the black gooney humps up his shoulders, pulls in his head and neck, and walks with quite a swagger—he looks real mean. They are shyer and more nervous than the white species. They will frequently attack human beings when molested, and for this reason are not as well liked as the tamer white goonies.

Short-Tailed Albatross:

The only other species of albatross that has been seen at Midway was a single example of the short-tailed albatross, a much larger species fully 10 feet in wing-spread, with an even larger, longer, more powerful beak, and a very deep croaky voice. It returned for two years to the Island, and then for some reason was injured and died. For a while it was setting on a black gooney egg. It was a much more powerful bird than the other two species, and could be held only with difficulty.

The Gooney That Could Remember Where It Was When It Was In The Egg:

One day we noticed that a white gooney had made a nest right in the middle of the road. So little by little we moved the egg, a foot at a time, over towards the side of the road. One of the parents always followed and sat on the egg, until eventually it was established in a nest at once side of the road at least 30 feet from where the egg was first laid. Both parents took turns sitting on the egg in the new locality. The change didn't seem to bother them. Then the egg hatched, and the young one when about two weeks old was left by itself. The next time we saw it it was right back where the original nest had been made in the middle of the road. It could remember where it belonged!

What really happened was that the first time the old bird returned to feed it, it insisted that the young bird return to the old nest-site before it would be fed. The old bird probably went directly to the old nest and waited for the young one to come over.

This completes the list of sea birds that nest at Midway. Since they nest here, and spend from two-thirds to three-fourths of their time here, this may be considered their natural home, for they leave only for a short period of a few months, probably remaining at sea wandering widely in search of food, and following schools of fish that are being chased by larger fish, sharks, seals, porpoises or whales. Certainly the smaller fish lead a harassed life, being attacked from below by the predators just mentioned and, when driven up out of the sea, are snapped out of the air by the sea birds. The smaller fish eat tiny fish, and these in turn eat minute crustaceans, and tiny larvae of crabs and lobsters, which in turn live upon even lower forms of life, microscopic plants and animals such as Diatoms, Protozoa, Infusoria, Foraminifera and Radiolaria which are present in all sea water in countless billions.

The complete list of sea birds is as follows:

White gooney	Brown booby	Grayback tern
Black gooney	Sooty-backed tern	Bosun bird
Frigate bird	Hawaiian tern	Wedge-tailed shearwater
Blue-faced booby	Noddy tern	Bonin petrel
Red-faced booby	Fairy tern	Bulwers petrel

The Land Birds on Midway

The four species of land birds inhabiting Midway are canaries, pigeons, finches and rails, exclusive of domestic fowl. All have been brought here from some other place—pigeons are raised at the Cable Company, and canaries have been turned loose, and are semi-wild but fed daily.

*The Laysan "Finch"**:

The finch and the rail were brought to Midway from Laysan Island, a small island between Midway and Honolulu. They are indigenous—or natives of Laysan Island. The finch is a very poor flyer, quite tame, slightly larger than a sparrow, with a rich yellow breast in the male. The finch is the worst pest on Midway. It destroys the young shoots, buds and flowers of ornamentals, vegetables and other cultivated plants, and is very destructive in this way. It nests in the ironwood trees.

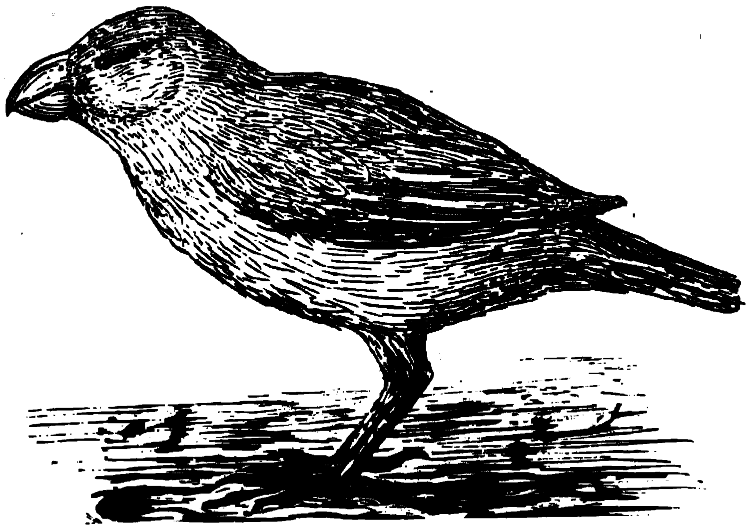


Fig. 29. The Laysan "finch."

The Laysan Rail:

On the other hand the Laysan rail, with short "stub" wings so small that it cannot fly, is insectivorous and certainly very beneficial. We have never seen it eat anything but flies, caterpillars, moths, and maggots. The Laysan rail is about 5 inches long, and stands about 4 inches high. The wings are so small they are hard to see, and then only when they are in a great hurry to get some place. It cannot fly at all, but is a very rapid runner. It is brown in color on the back, the whole under parts blue-gray, looks something like a small quail, has bright little red eyes and green beak, legs and feet. If you make no swift or suddent movement, but sit real still they will come right up to you and run around and between your feet, looking for flies. They pick flies right out of the air! But more often they stay around broken eggs or dead birds getting the flies that are attracted to the

* The so-called Laysan Finch is actually *Telespiza cantans*, a member of the endemic Hawaiian family Drepanididae. The true finches belong to the Fringillidae.

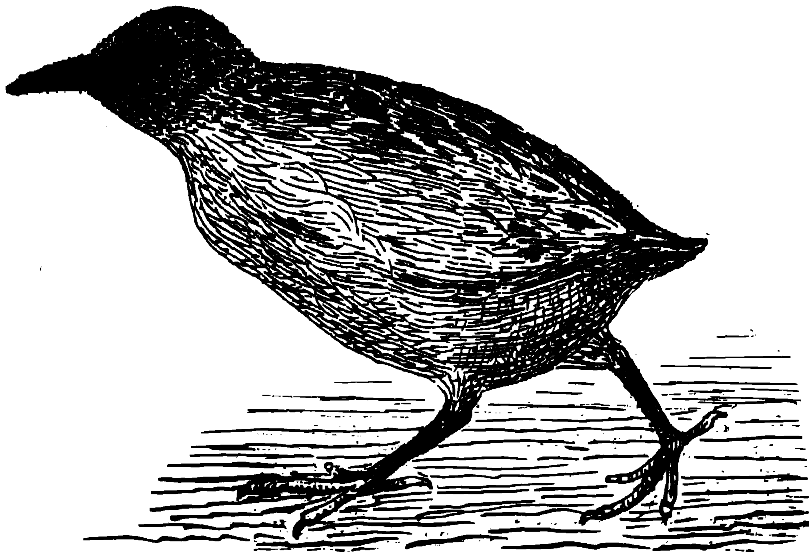


Fig. 30. The Laysan rail.

carrion. When the maggots are emerging and going into the ground to pupate, the rails dig them up by flipping the sand sidewise with the beak. They also diligently search all grass and other plants looking for caterpillars and moths which they relish. The rail may be considered the most beneficial bird on Midway.

The Laysan rail is about one-third the size of the Wake Island rail. The Wake rail is also flightless and is a native of Wake. It is a distinct or different species from the Laysan rail.

During the breeding season our rail becomes somewhat noisy. For its size it can make quite a racket, a good term for its peculiar chattering cry. It nests on the ground, hiding the nest in the grass or bushes, and lining the nest with grass. The egg is about 1⅛ inches long; two or three may be laid. The baby rail, only an inch long, when 4 or 5 days old, can run as fast as the older birds. It soon learns to find its own food, as it is taught to do so by the older birds which carefully guard it for the first month. When only 2 or 3 days old the little rail looks like a black velvet marble rolling along the ground. Its little feet and legs are so small and move so fast that they can hardly be seen.

Migratory Shore Birds:

Although the nearest large body of land in any direction from Midway is 2,000 miles away, there are certain land birds that regularly stop at Midway on their way to the larger Hawaiian Islands and Samoa.

Most commonly seen prowling around on the lawns of the P.A.A. hotel is the Pacific golden plover which comes down from Siberia, the Aleutian Islands, or Alaska. A few may stay here over the winter. Others go on down to Samoa, Tahiti or even perhaps New Zealand—another 4,500 miles! They must fly "non stop" the entire 1,600 miles from the nearest Aleutian Island to Midway. They do not have webbed feet, and cannot stay on the water for more than a very short time without drowning.

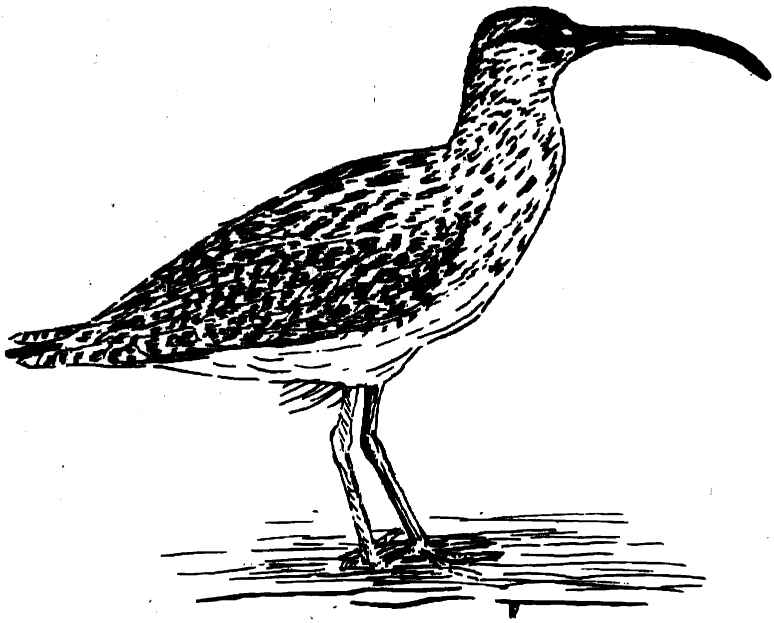


Fig. 31. The bristle-thighed curlew.

Also regular migrants are the "wandering tattler," "turnstone" and "bristle-thighed curlew." The latter is the bird with the long, downward curved beak, which is almost as long as its body. It is as large as a small chicken, but has long legs. Its cry of "Kee wee—Kee wee" when disturbed is distinct from all other bird cries.

Storms Bring Strangers:

The strong winds, often 30 to 60 miles per hour, of our frequent winter storms from January through April, often "blow in" strange birds.

These include several species of wild duck, bittern, hawk and goatsucker (night-jar or whippoorwill). They are often captured, being too tired upon arrival to try to escape. Most of them die after a few days on Midway.

Two species of sea gulls are also blown in by storms, but they stay only a few days.

Large dragon flies, and the monarch butterfly, also appear in fairly large numbers after storms. They all die off in a few weeks' time.

Fish-net floats, glass balls from 2 to 18 inches in diameter, wash ashore during storms. Some have Japanese characters, other have the Russian hammer and sickle impressed in the glass.

In August or September the stinging Portuguese man-of-war, a small blue jellyfish, may appear. It is best not to go swimming if they are present in large numbers.

Acknowledgments

I am indebted to Walter Donaghho of Honolulu for identifications of some of the birds mentioned in this article.

G. C. Munro of Honolulu furnished the pictures of the huts and Capt. Walker's house on Midway.

Dr. F. X. Williams of Honolulu made all of the pen and pencil drawings, from life while at Midway.

The crayon cartoons were made by J. C. Littig of Manila, while on the California clipper between Midway and Honolulu.

The Bishop Museum furnished the photographs of the boobies and frigate birds.

To the above and also to others who have helped me in writing this article I hereby express my gratitude.

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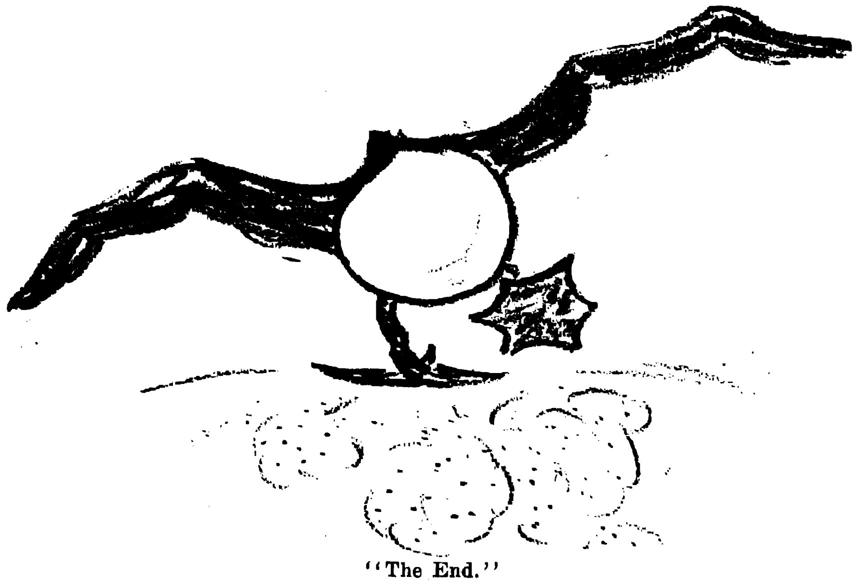

"The End."

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
MARCH 17, 1941, TO JUNE 11, 1941

Date	Per pound	Per ton	Remarks
Mar. 17, 1941........	3.33¢	$66.60	Philippines.
" 18.............	3.35	67.00	Cubas; Philippines; Puerto Ricos.
" 19.............	3.34	66.80	Cubas.
" 21.............	3.32	66.40	Cubas.
" 24.............	3.425	68.50	Puerto Ricos, 3.40; Cubas, 3.45.
" 31.............	3.40	68.00	Puerto Ricos.
April 17.............	3.30	66.00	Puerto Ricos.
May 5.............	3.435	68.70	Puerto Ricos, 3.42, 3.45; Philippines, 3.45.
" 9.............	3.39	67.80	Puerto Ricos, 3.38, 3.40.
" 14.............	3.38	67.60	Puerto Ricos.
" 20.............	3.34	66.80	Cubas, 3.35; Puerto Ricos, 3.33.
" 23.............	3.33	66.60	Puerto Ricos.
" 24.............	3.38	67.60	Philippines.
" 27.............	3.375	67.50	Cubas, 3.37; Puerto Ricos, 3.38.
" 28.............	3.4075	68.15	Puerto Ricos, 3.395, 3.42.
" 29.............	3.45	69.00	Puerto Ricos; Philippines.
June 5.............	3.40	68.00	Puerto Ricos.
" 6.............	3.405	68.10	Puerto Ricos, 3.40; Philippines, 3.41.
" 9.............	3.44	68.80	Puerto Ricos, 3.43; Cubas, 3.45.
" 10.............	3.45	69.00	Philippines; Puerto Ricos.
" 11.............	3.50	70.00	Philippines; Puerto Ricos.

M. F.

THE HAWAIIAN

PLANTERS' RECORD

Vol. XLV FOURTH QUARTER 1941 No. 4

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Composition of Sugar Cane Plants Grown in Deficient Nutrient Solutions:

In using leaves and sheaths as indices of the levels of the various nutrients in cane, it is necessary to know the effects of serious deficiencies not only upon the levels of N–P–K, but also upon sugars and water. In this study, the variety 31–2806 was grown in deficient nutrient solutions which included a complete nutrient solution as the control, and each of the remaining nine cultures was deficient in one of the following nine elements: nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, and boron.

Upon harvest the plants were separated into their various parts (see Fig. 1) and each part analyzed for moisture, carbohydrate, nitrogen, phosphorus, potassium, and calcium.

Of considerable importance is the fact that no matter what the deficiency from which the plant was suffering, the moisture level of the elongating cane sheaths correlated ($.821 \pm .109$) very well with the moisture level of the entire plant. Another correlation observed is that with the exception of the minus-iron culture, there is a good inverse correlation between the sugar level of the sheath and the quality ratio of the cane ($r = -.800 \pm .128$). Finally, each mineral deficiency had a marked effect not only on the total amount of N–P–K absorbed, but upon the balance among them.

Cane Growth Studies—Factors Which Influence Yields and Composition of Sugar Cane:

Further research concerned with some of the factors which influence yields and composition of sugar cane has identified certain interactions which are involved. Definite effects were measured from different soils, from different varieties, and from different levels of fertilization but these were all considerably modified by the differences in climatic influences, chiefly sunlight and temperature, under which the crops were grown.

Soil and Plant Material Analyses by Rapid Chemical Methods—III:

A gradual extension of the field in which rapid chemical methods of analysis (R.C.M.) are being applied has brought about the development of new procedures and the modification of some of the older ones for special purposes. These are described in detail. Ten years employment of R.C.M. by ourselves and agricultural workers in other countries has rendered it necessary to clarify a number of tables and explanatory matter in the two bulletins issued by this Experiment Station on the subject. The present paper is intended to record and classify all major developments in R.C.M. up to the end of 1941. It will be issued as Bulletin No. 53 of the Experiment Station, H.S.P.A. Agricultural and Chemical Series.

Composition of Sugar Cane Plants Grown in Deficient Nutrient Solutions*

By Harry F. Clements, J. P. Martin and S. Moriguchi

Any attempt to use the Index Method (1) in determining the fertilizer requirements of cane crops must be based upon a background of knowledge involving the behavior of the plants toward certain known nutritional circumstances. Although cane growing under field conditions will rarely suffer mineral deficiencies as acute as those observed in deficient nutrient solutions, the opportunity to study plants so produced was presented as a result of the plants grown at the Experiment Station H. S. P. A. Four varieties, H 109, 32–1063, 32–8560, and 31–2806, were grown in culture solutions as already described by Martin (6). He noted that some varieties manifested a much higher degree of tolerance to certain deficiencies than others and that varieties have different nutritional requirements. Further, Martin has already reported on the general reactions of the first three varieties (7). The variety 31–2806 was removed from the culture solutions December 18, 1940, and was used to obtain information regarding the composition of the different parts of plant with reference to reducing sugars, sucrose, acid-hydrolyzable carbohydrates, moisture, total nitrogen, potash, phosphorus, and calcium.

Experimental

Upon removal from the culture solutions, each plant was divided into its various parts (Fig. 1). Starting at the bottom of the stalk after the roots were removed and discarded, the millable cane was cut into three internode units. The lowest three internodes are called the "1st 3 internodes," the next three, the "2d 3 internodes," etc., up to the joint carrying a leaf. The green top representing the metabolically active part was then divided. Beginning with the spindle leaf as No. 1, the leaves were counted successively downward. The oldest leaves up to and including leaf No. 7 were removed from the cane and divided into blades (green-leaf blades) and sheaths (green-leaf sheaths). The piece of cane exposed by the removal of these leaves was then cut just below leaf No. 6, and labelled "green-leaf cane." Leaves 3, 4, 5, and 6 were next removed, and divided into blades (elongating cane blades) and sheaths (elongating cane sheaths). The piece of cane exposed by these removals was cut off just below leaf No. 2 and labelled "elongating cane." The remaining portion was then divided into two parts by cutting off five inches of the soft, white bottom (meristem) and leaving the top (spindle cluster). In some cases, because of the scarcity of material, it was necessary to combine some of these fractions.

The methods of analysis employed were the same as those used in previous studies (1).

* Published by permission of the Director of the Hawaii Agricultural Experiment Station as Technical Paper No. 92.

RESULTS

When the plants were divided into their various parts, each part was weighed. These weights are recorded in Table I.

TABLE I

GREEN WEIGHTS OF PLANT PARTS

(Grams)

	Complete	—N	—P	—K	—Ca	—Mg	—S	—Fe	—Mn	—B
1st 3 internodes	217	57	177	131	195	103	195	136	129	169
2d 3 internodes	225	46	180	121	108	71	173	109	180	97
3d 3 internodes	176		140	141		43			168	
Top internodes	236		80	44		36	90		100	72
Green-leaf cane	140	10	48	40			103	28	170	28*
Elongating cane + meristem	44		15	34		17	36	9	60	
Elongating cane sheaths	78	25	54	42		58	50	31	67	52*
Green-leaf sheaths	49		28	18			41	26	54	
Elongating cane blades	115	29	79	63		97	52	61	89	45*
Green-leaf blades	83		42	24			39	49	97	
Spindle cluster	97	14	43	58		75	23	27	96	70*
Total	1460	181	886	716	303	500	802	476	1210	533

* These weights are taken from the lalas, the original top having been killed.

An examination of Table I reveals the relative severity of the various deficiencies as measured by the actual growth made in each case. In all cases, there appear to have been an actual physiological deficiency strikingly revealed in the amount of leaf growth made. In Table II, the ratio of leaf weight of deficiency plants vs. the control plant produced in complete nutrient and the ratio of the total plant weight of deficiency plants vs. the control are recorded. Also reported in Table II is a statement regarding the leaf color range in culture.

TABLE II

DEFICIENCIES AND LEAF GROWTH

Nutrient culture	Ratio leaf weight $\frac{\text{deficiencies}}{\text{Complete}}$	Ratio total weight $\frac{\text{deficiencies}}{\text{Complete}}$	Leaf color range
Complete			Light green to dark green
—N	.146	.124	Yellow green
—P	.556	.605	Light green to green
—K	.491	.490	Light green to green
—Ca	0	.208	No leaves
—Mg	.583	.344	Yellow-green
—S	.380	.548	Yellow-green to light green
—Fe	.465	.327	White to yellow-green
—Mn	.956	.828	Yellow-green to light green
—B	0	.365	Dark green (lala leaves)

So far as N, P, and K deficiency effects are concerned, the total weight of the plant is rather closely related to the leaf weight. One might under field conditions

expect to find various levels of these materials affecting the leaf areas which in turn would affect the amount of cane weight produced. Of the remaining elements, the leaf weight ratios exceed total weight ratios in the cases of Fe, Mg, and Mn. Since Mg is a constituent of chlorophyll and Fe is essential to the formation of the pigment, it is understandable that deficiencies of these materials lower the efficiency of the leaves. The fact that Mn also falls into this category suggests its function as being at least somewhat related.

The remaining deficiencies, —Ca, —S, and —B, give leaf ratios below the total weight ratios. The effects of Ca and B deficiencies are so violent that the whole green tops are killed. The effects of S deficiency are mild by comparison.

In Table III are recorded the moisture contents of the various plant parts produced in the deficiency series.

TABLE III

MOISTURE CONTENT

(% Green Weight)

	Complete	—N	—P	—K	—Ca	—Mg	—S	—Fe	—Mn	—B
1st 3 internodes	68.2	73.7	68.4	74.0	72.3	79.6	72.3	69.9	66.7	79.3
2d 3 internodes	68.4	78.3	70.0	75.2	72.2	80.3	73.8	72.5	66.9	79.4
3d 3 internodes	69.3		73.6	75.1		82.6			69.6	
Top internodes	72.5		78.8	78.4		80.6	75.6		72.0	81.9
Green-leaf cane	79.3	95.0	85.4	78.8			79.6	82.1	79.7	85.7
Elongating cane and meristem	88.6		93.3	88.2		94.1	87.5	88.9	88.3	
Elongating cane sheaths	76.9	84.0	78.7	76.2		83.6	80.0	79.0	76.9	83.7
Green-leaf sheaths	75.5		78.3	77.8			78.1	80.8	74.1	
Elongating cane blades	71.3	72.4	70.2	69.8		72.2	71.2	72.1	71.4	76.7
Green-leaf blades	71.1		70.3	66.7			69.2	71.4	71.1	
Spindle cluster	75.3	78.6	77.9	75.9		78.7	78.3	77.8	77.1	78.6
Moisture per cent for whole plant	72.5	77.7	73.5	76.4	...	79.4	75.1	73.8	72.9	80.1

In general, it may be said that whatever differences exist in the moisture percentages of old tissues, they tend to be reduced in younger tissues. However, in most instances the level of moisture in the elongating cane sheaths serves as an index to the general moisture level of the whole plant. In only the case of —K is there a serious departure from this relationship. The correlation existing between the moisture level of the young sheaths and the moisture level of the entire plant is $+ .821 \pm .109$

Results of analysis of the various tissues for reducing sugars, sucrose and acid-hydrolyzable materials are reported in Tables IV, V, and VI, respectively.

TABLE IV

REDUCING SUGARS

(% Dry Weight)

	Complete	—N	—P	—K	—Ca	—Mg	—S	—Fe	—Mn	—B
1st 3 internodes	.4	1.6	.4	2.1	0.3	0.3	0.9	0.3	0.5	.6
2d 3 internodes	.4	1.8	.4	6.2	0.5	.2	1.5	1.2	.3	.6
3d 3 internodes	.6		.4	8.8		.3			.3	
Top internodes	.6		1.1	7.3		.3	4.5		.3	.6
Green-leaf cane	1.7		3.1	12.1			4.7	.3	2.6	2.0
Elongating cane and meristem	2.9		1.8	11.2		.6	10.1	.6	6.4	
Elongating cane sheaths	.6	.8	.9	7.6		.3	3.1	2.2	1.9	2.5
Green-leaf sheaths	.6		.4	6.1			1.7	1.4	1.0	
Elongating cane blades	.2	.7	.1	1.0		.2	.9	.2	.2	.2
Green-leaf blades	.3		.1	1.5			1.1	.3	.5	
Spindle cluster	1.6	1.5	.6	3.1		.5	1.1	.8	1.3	.9

TABLE V

SUCROSE

(% Dry Weight)

	Complete	—N	—P	—K	—Ca	—Mg	—S	—Fe	—Mn	—B
1st 3 internodes	36.7	46.2	41.8	42.7	50.0	28.5	37.3	26.4	39.7	37.4
2d 3 internodes	36.3	40.1	42.2	39.2	51.6	30.5	38.4	26.2	38.7	37.3
3d 3 internodes	37.1		39.5	32.0		25.7			40.3	
Top internodes	39.3		32.5	28.9		11.8	32.9		41.4	35.4
Green-leaf cane	33.3		18.0	20.8			25.5	26.6	32.3	15.0
Elongating cane and meristem	14.0		3.5	14.6		8.6	11.4	10.1	13.7	
Elongating cane sheaths	6.1	8.5	9.4	6.8		2.1	6.4	17.8	10.2	5.8
Green-leaf sheaths	6.0		9.4	8.0			14.6	12.8	8.1	
Elongating cane blades	4.8	3.6	3.4	4.8		5.0	3.3	5.3	3.6	2.7
Green-leaf blades	5.8		4.2	3.2			3.3	6.0	4.6	
Spindle cluster	4.4	4.4	4.0	3.7		2.9	4.0	4.7	4.1	2.6

TABLE VI

ACID-HYDROLYZABLE CARBOHYDRATE

(% Dry Weight)

	Complete	—N	—P	—K	—Ca	—Mg	—S	—Fe	—Mn	—B
1st 3 internodes	3.9	5.0	4.6	4.9	3.6	4.9	5.1	4.4	5.1	4.5
2d 3 internodes	4.7	5.4	4.9	4.8	4.1	4.7	5.1	4.3	5.1	4.7
3d 3 internodes	4.6		5.2	4.8		6.1			5.3	
Top internodes	5.3		5.6	5.6		7.0	5.6		5.7	4.9
Green-leaf cane	6.3		7.6	6.6			6.2	6.1	6.1	12.9
Elongating cane and meristem	11.1		4.0	10.8		11.1	13.8	12.5	11.1	
Elongating cane sheaths	16.2	19.5	19.6	17.7		17.1	19.1	15.8	18.3	18.5
Green-leaf sheaths	17.8		19.6	16.7			18.0	15.6	18.8	
Elongating cane blades	19.5	20.4	19.3	16.6		16.2	22.1	16.0	17.4	17.3
Green-leaf blades	18.1		18.7	17.9			20.1	16.0	18.4	
Spindle cluster	20.5	20.1	20.6	17.9		18.5	21.0	18.0	20.0	17.6

So far as the reducing sugars are concerned, the —K culture is the only one in which the reducing sugars are unusually high (2, 3). Whether this is due to the actual deficiency of potassium or to the increased absorption of calcium (see Table XI) remains to be determined.

Sucrose in the millable cane of the complete culture solution is not so high as usually obtains in the field, but is higher in the —N, —P, —Ca, and —Mn cultures. In the —Mg and —Fe cultures, the cane produces the lowest amount of storage sugar, while in the remaining cultures there is little difference.

So far as the acid-hydrolyzable carbohydrates are concerned, nothing of any moment appears in the data, except that the amount of this material in the cane is considerably lower than in cane grown under field conditions.

In Table VI are reported the data for the total sugars of the plant, representing the combined sucrose and reducing sugars. Physiologically, such a combination is justifiable since both forms are readily available to the plant for growth and since the two forms are so readily interconvertible (4, 5). Just what the factors are which affect the balance between the two in storage cane remains to be worked out.

TABLE VII

TOTAL SUGARS

(% Dry Weight)

	Complete	—N	—P	—K	—Ca	—Mg	—S	—Fe	—Mn	—B
1st 3 internodes	37.1	47.8	42.2	44.8	50.3	28.3	38.2	26.7	40.7	38.0
2d 3 internodes	36.7	41.9	42.6	45.4	52.1	30.7	39.9	27.4	39.0	37.9
3d 3 internodes	37.8		39.9	40.8		26.0			40.6	
Top internodes	39.9		33.6	36.2		12.1	37.4		41.7	36.0
Green-leaf cane	35.0		21.1	32.9			30.2	26.9	35.9	17.0
Elongating cane and meristem	16.9		5.3	25.8		9.2	21.5	10.7	20.1	
Elongating cane sheaths	6.7	9.3	10.3	14.4		2.4	9.5	20.0	12.1	8.3
Green-leaf sheaths	6.6		9.8	14.1			16.3	14.2	9.1	
Elongating cane blades	5.0	4.3	3.5	5.8		5.2	4.2	5.5	3.8	2.8
Green-leaf blades	6.1		4.3	4.7			4.4	6.3	5.1	
Spindle cluster	6.0	5.9	4.6	6.7		3.4	5.1	5.5	4.4	3.6
Calculated Q. R.	9.2	9.9	9.1	10.9	7.1	19.4	10.4	13.3	8.7	13.2

There appear in this table several correlations worth noting. The quality of the cane in all the deficiencies except —Fe, —B, and —Mg is about the same as the control, which means that the deficiencies are related for the most part to a decrease in growth activities and very slightly to the proportion of carbohydrate material used in growth or storage. Fe and Mg are both intimately connected with chlorophyll formation and, in addition, Fe is important in respiration; hence one can expect storage and sugar movement to be interfered with. Any element (such as Mg and Fe), which is involved in photosynthesis, is likely in its absence to affect storage adversely. Any element (such as Fe), which will interfere with respiration, is likely to affect the movement of sugar into the main storage tissue and will result in an accumulation of sugar in the sheath tissue. This, no

doubt, accounts for the high sugar values in the sheaths of the —Fe series. The poorer quality of the —B culture is related not to the amount of sugar in the cane, but rather to a higher moisture content. The high quality of the minus calcium culture fits with the observations made by Verret (9) that application of lime to cane under field conditions causes poorer juices.

Another observation worthy of note is that in all cases except —Mg, the level of the total sugars in the sheaths is higher than in the control, which suggests the relationship previously pointed out that any interference with the balance between carbohydrate production and utilization will be reflected in the level of sheath sugars. Thus, a reduction in growth without a corresponding reduction in photosynthesis will raise the level of sheath sugar. An increase in growth will lower the level of sheath sugars. A decrease in photosynthetic efficiency (—Mg) will obviously reduce the sheath sugar level. That the relationship between the sheath sugar level and the growth made is not more striking is probably caused by the advanced stages of disintegration of such cultures as —N, —K, etc.

The final observation to be made from Table VII is that with the exception of the —Fe culture there is a rather good inverse correlation between the quality ratio of the cane and the total sugar level of the elongating cane sheaths ($r = -.800 \pm .128$). Since a deficiency of iron affects the sugar translocation mechanism, it is reasonable to expect a blockage of sugar in the top portion and a lowering of the sugar level in the cane.

Mineral Composition

All the samples collected were subjected to analysis for total nitrogen, phosphorus, potassium, and calcium. The results are reported in Tables VIII to XI.

TABLE VIII

TOTAL NITROGEN

(% Dry Matter)

	Complete	—N	—P	—K	—Ca	—Mg	—S	—Fe	—Mn	—B
1st 3 internodes	1.06	.13	1.37	.51	1.13	1.08	1.45	1.04	.68	.98
2d 3 internodes	1.13	.25	1.12	.60	.87	1.21	1.05	1.21	.75	.73
3d 3 internodes	1.15		1.02	.66		1.30			.88	
Top internodes	.91		.87	.63		1.82	.93	1.4	.86	.60
Green-leaf cane	.68	.88	.94	.74			.86	1.46	.75	.79
Elongating cane and meristem	1.46		2.10	1.32		2.40	1.10	2.14	.60	
Elongating cane sheaths	.32	.33	.37	.51		.70	.45	.57	.36	.51
Green-leaf cane sheaths	.33		.28	.42			.39	.43	.32	
Elongating cane blades	.95	.78	.92	1.20		1.13	.57	.87	1.04	1.52
Green-leaf cane blades	1.02		.92	.94			.47	.84	1.10	
Spindle cluster	.76	.70	.86	1.12		1.26	.62	.94	.93	1.16

TABLE IX

PHOSPHORUS (P_2O_5)

(% Dry Matter)

	Complete	—N	—P	—K	—Ca	—Mg	—S	—Fe	—Mn	—B
1st 3 internodes	.41	.92	.02	.48	.98	.92	.46	.46	.37	.71
2d 3 internodes	.34	1.01	.06	.27	1.12	1.15	.46	.62	.27	.71
3d 3 internodes	.30		.07	.27		1.03			.25	
Top internodes	.27		.07	.32		1.24	.37		.27	.71
Green-leaf cane	.34	2.29	.14	.34			.34	.78	.41	
Elongating cane and meristem	1.10		.76	.85		1.03	.53	1.95	.87	1.21
Elongating cane sheaths	.32	1.33	.12	.53		1.61	.55	.94	.46	.62
Green-leaf cane sheaths	.27		.07	.48			.48	.39	.23	
Elongating cane blades	.39	1.67	.14	.64			.46	.90	.41	.64
Green-leaf cane blades	.32		.11	.76		.71	.37	.55	.34	
Spindle cluster	.57	.96	.27	.66		.90	.48	.90	.60	.66

TABLE X

TOTAL POTASSIUM (K_2O)

(% Dry Matter)

	Complete	—N	—P	—K	—Ca	—Mg	—S	—Fe	—Mn	—B
1st 3 internodes	.75	1.91	.65	.05	1.73	1.61	1.13	1.36	.74	2.18
2d 3 internodes	.93	2.93	1.17	.16	2.94	2.04	1.52	2.17	.81	2.28
3d 3 internodes	1.13		1.99	.22		1.96			1.04	
Top internodes	1.66		3.03	.06		2.20	1.77		1.46	3.12
Green-leaf cane	2.69	6.74	4.22	.11			2.44	2.55	2.49	3.79
Elongating cane and meristem	5.67		7.95	1.23		5.70	3.70	5.23	5.52	
Elongating cane sheaths	3.05	4.79	3.90	.29		5.07	3.61	4.69	3.21	4.01
Green-leaf cane sheaths	2.76		2.69	.30			3.06	3.01	2.43	
Elongating cane blades	2.76	3.01	2.12	.38		2.88	1.84	3.25	2.25	6.16
Green-leaf blades	2.60		2.38	.18			1.67	3.29	2.18	
Spindle cluster	2.98	3.18	2.77	1.37		3.37	2.24	1.73	2.96	3.05

TABLE XI

TOTAL CALCIUM (Ca)

(% Dry Matter)

	Complete	—N	—P	—K	—Ca	—Mg	—S	—Fe	—Mn	—B
1st 3 internodes	.04	.04	.05	.10	.02	.09	.06	.09	.06	.06
2d 3 internodes	.06	.06	.08	.10	.02	.16	.06	.12	.04	.08
3d 3 internodes	.06		.10	.14		.22			.06	
Top internodes	.07		.14	.18		.30	.08		.07	.12
Green-leaf cane	.09	.450	.23	.20			.11	.24	.10	.21
Elongating cane and meristem	.24		.10	.42		.32	.23	.36	.29	
Elongating cane sheaths	.14		.19	.38		.73	.16	.22	.15	.18
Green-leaf cane sheaths	.17		.22	.36			.18	.24	.20	
Elongating cane blades	.23		.27	.74		.46	.31	.32	.26	.25
Green-leaf blades	.46		.41	.94			.56	.83	.54	
Spindle cluster	.12		.17	.31		.28	.18	.19	.15	.16

There are two general ways of evaluating mineral compositions of plants. In the first case, each element is looked upon as an entity in relation to the dry matter of the various tissues of the plant and is therefore treated separately. In the second case, the three elements most commonly deficient under field conditions, N, P, and K, are looked upon as inseparable and are therefore combined into an N–P–K unit (8) and examined not only on the basis of the total amount of the three (intensity) but also upon the basis of the relative amounts of each (quality) in the young leaves. Both approaches will be followed in this paper.

In Table VIII, the nitrogen compositions of the various tissues of plants produced in the culture series are reported. The amounts of nitrogen in the top portions of the plant grown in the complete nutrient solution are very similar to those produced under field conditions. However, the nitrogen in the cane is about ten times higher than that associated with 31–1389 produced at Waipio. Such a fact means that the plants in the complete nutrient solution were absorbing much more of the element than they could use. In the minus-nitrogen culture, it is clear that deficiency is shown throughout the plant, although the plant maintains a disproportionate amount of nitrogen in its tops at the expense of the nitrogen in the cane. The interpretation would be that it removes nitrogen from the old tissues and uses it in the young tissues. Deficiencies of phosphorus and magnesium seem to result in a slight accumulation of nitrogen in the various tissues, while deficiencies of sulphur and iron result in normal nitrogen levels in the old tissues but reduced amounts in the leaf tissues. Deficiencies of manganese and potassium result in lower nitrogen levels in the cane but nearly normal levels in the tops.

Phosphorus: The phosphorus composition of the various tissues is reported in Table IX. The P_2O_5 content of the various tissues of the plant produced in the complete nutrient solutions is somewhat higher than that found in a field-grown crop. As in the case of nitrogen, the P_2O_5 content of the plant produced in the —P solution is relatively much lower in the old cane than in the tops. Plants grown in —N, —Ca, —Mg, —Fe and —B contain a higher percentage of P_2O_5 than does the normal plant. —K does not affect the P_2O_5 composition nor does —Mn. The —S culture has increased the proportion of P_2O_5 contained in the tissues.

Potassium: The level of potash in the plant grown in the complete nutrient solution is somewhat higher than found in field-grown cane, but the distribution of this material in the various plant parts is the same. The percentage composition of potassium is materially increased in the —N, —Ca, —Mg, —Fe and —B series. —P seems to result in an accumulation of potassium in the young portion of the stem without affecting the composition in other parts. —S, on the other hand, causes a slight accumulation in old cane and sheaths but a reduction in the young tissues. Manganese deficiency does not appear to affect the potassium content of the plant.

Calcium: The calcium content of the various tissues of the control plant is remarkably similar to that found in field-grown plants. The —K, and —Mg plants have a calcium content considerably higher than normal, while —Fe plants are slightly above the control in their calcium composition. Deficiencies of phosphorus, manganese, boron, sulphur do not affect the calcium composition. The minus

nitrogen plant has normal amounts of calcium in the old cane but very high amounts in the young cane. Lack of material made analysis of the green tissues impossible.

Turning now to the second method of analysis (8), the amounts of nitrogen (N), phosphorus (P_2O_5), and potash (K_2O) in the elongating cane leaves of the various cultures are shown in Table XII. In the last column, the intensity factor which is the sum of columns 2, 3, and 4 is reported for each culture.

TABLE XII

QUANTITATIVE EVALUATION OF THE N-P-K UNIT

(% Dry Weight—Young Leaves)

Culture	% Nitrogen (N)	% Phosphorus (P_2O_5)	% Potassium (K_2O)	Intensity
Complete	.95	.39	2.76	4.10
—Nitrogen	.78	1.67	3.01	5.46
—Phosphorus	.92	.14	2.12	3.18
—Potassium	1.20	.64	.38	2.22
—Calcium	...	...	...	
—Magnesium	1.13	.71	2.88	4.72
—Sulphur	.57	.46	1.84	2.87
—Iron	.87	.90	3.25	5.02
—Manganese	1.04	.41	2.25	3.70
—Boron	1.52	.64	6.16	8.32

From the viewpoint of the nutritional intensity, it is clear that all the treatments had a tremendous effect on the amounts of the materials (N–P–K). Some of the deficiencies caused a material increase in salt absorbed (—N, —Mg, —Fe, —B) while others caused a decrease (—P, —K, —S, —Mn). The average intensity factor for the field-grown crop of 31–1389 was 2.90 at Waipio and 3.285 at Kailua, while that of the control in this series was 4.10 showing a considerably greater intensity in the solution-grown plants.

The qualitative evaluation of the N–P–K unit is shown in Table XIII. To arrive at this value, each material, N, P_2O_5, and K_2O, is converted into milliequivalents and is expressed on the basis of a hundred units. Thus, the sum of each N–P–K unit quality equals 100.

TABLE XIII

QUALITATIVE EVALUATION OF THE N-P-K UNIT

	N	P_2O_5	K_2O	Intensity factor from Table XII
Complete*	10.09	2.46	87.45*	4.10
—Nitrogen	7.26	9.19	83.55	5.46
—Phosphorus	12.34	1.13	86.53	3.18
—Potassium	44.24	13.97	41.89	2.22
—Calcium	....	....	....	...
—Magnesium	15.78	5.88	78.35	4.72
—Sulphur	9.00	4.30	86.70	2.87
—Iron	7.84	4.80	87.36	5.02
—Manganese	13.01	3.03	83.96	3.70
—Boron	7.49	1.87	90.64	8.32

* The quality of the N–P–K unit of field-grown 31–1389 is (N) 18.17, (P_2O_5) 3.05, and (K_2O) 78.78, at Waipio and (N) 16.58, (P_2O_5) 2.09 and (K_2O) 81.33 at Kailua.

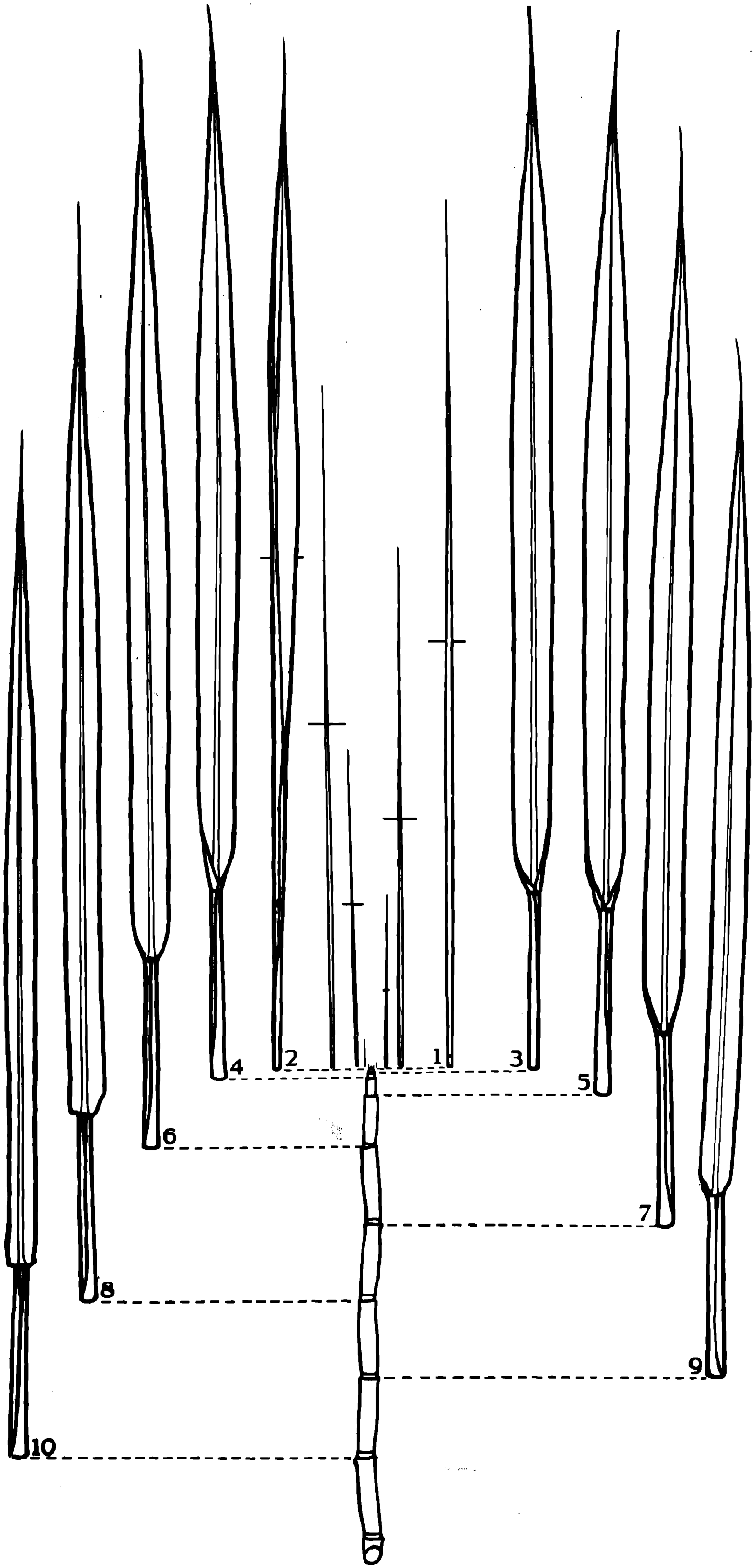

Fig. 1

Fig. 1. A sugar cane stalk of the variety 32–8560 separated into its various parts. These parts were traced on a large sheet of paper and the tracing photographed. Leaf No. 1 in the drawing was the spindle leaf of the intact plant and the other leaves were counted progressively downward. The small leaves within No. 1 cannot be seen in the intact plant since they are enclosed by the spindle leaf. The horizontal lines across leaves 2, 1 and those within represent the width of each of the leaves when fully unrolled. Since the drawing was made to scale, the length of the blades and sheaths of the leaves as indicated is a true indication of growth made. Thus, although the blade of leaf No. 1 has nearly reached its full length, the sheath has attained only a small fraction of its length. The sheath of leaf No. 2 is about half-grown and that of leaf No. 3 has nearly completed its growth.

The position which each leaf occupied on the stem is indicated by the broken horizontal line. The internodes below the attachment of leaf No. 6 seem to have attained their full length. The four internodes above are in various stages of elongation. At the very tip of the stem is the meristem.

In the studies reported in this paper, a stalk is taken and the dry-leaf cane is cut off from the green top just below the node carrying the last living leaf. In the case of the figure, that was at the node of leaf No. 10. The dry cane is further divided into three internode units beginning from the bottom.

The green top is divided into several parts as follows: The green leaves are removed up to and including leaf No. 7. (The spindle leaf is No. 1, and the others are numbered downward.) Although the number of leaves between No. 7 and the oldest varies, in the figure, leaves 7, 8, 9, and 10 would constitute the sample. These leaves are then separated into blades and sheaths. The blades of these leaves are called green-leaf blades and the sheaths, green-leaf sheaths. The stalk which has been exposed in removing these leaves is cut off just below the node of leaf No. 6. The sample is called green-leaf cane. It is to be noted that the internodes of this sample have reached their full length. Frequently, however, the upper internodes of this sample have yet to complete the growth in diameter.

Leaves 6, 5, 4, and 3 are next removed and separated into blades and sheaths. The blades are spoken of as the elongating cane blades and the elongating cane sheaths, respectively. The stem exposed by the removal of these leaves is cut off just below Joint No. 2 and is labeled elongating cane. The blades and sheaths are the critical tissues used to determine the levels of the various materials within the plant. The elongating cane sample is so-called because it is in this region the vertical elongation is taking place.

The material which remains now is made up of leaves Nos. 2 and 1 and the enclosed leaves as well as the very tip of the stem. About five inches of the base are removed and called the meristematic material, and the remaining upper part is called the spindle cluster.

The data in Table XIII indicate certain relationships which are worthy of note. The amounts of the three nutrients in the control are somewhat lower in nitrogen and higher in potash than in field-grown plants, but about the average with respect to phosphorus. It should be remembered, however, that the intensity of nutrition for the controls is considerably greater than for field-grown plants. Nitrogen deficiency increases the intensity factor and increases the absorption of phosphorus many times. Phosphorus deficiency reduces the intensity factor but disturbs the quality only through a reduction in P_2O_5. Potassium deficiency causes an enormous reduction of the intensity factor by its own absence, but greatly increases the balance of both phosphorus and nitrogen. Magnesium deficiency increases the intensity factor, and also increases the nitrogen and phosphorus portion of the N–P–K unit. Sulphur deficiency causes a large reduction in intensity and an increase in phosphorus at the expense of nitrogen in the unit. Iron deficiency affects the N–P–K nutrition by increasing the intensity factor and causes an increase in the relative amount of phosphorus at the expense of nitrogen. Manganese deficiency results in a reduced intensity factor, although within that reduction there is a relative increase of nitrogen and phosphorus at the expense of potash. Boron deficiency causes a doubling of the intensity factor and also a proportional increase in the amounts of potassium at the expense of phosphorus and nitrogen.

Summary

1. Plants of the variety 31–2806, after being grown in various deficiency solutions, were subjected to analysis for moisture, reducing sugars, sucrose, total sugars, acid-hydrolyzable carbohydrates, total nitrogen, potash, phosphorus and calcium.

2. All the deficiencies have marked effects in the amount of leaf growth produced. —N, —P, and —K produce reductions in leaf growth which are very nearly reflected in the total amount of growth made.

3. Considerable differences exist in the moisture content of plants produced in the various cultures. In each case, the moisture content of the young leaf sheath is a good index to the general moisture status of the whole plant.

4. Reducing sugars are low in all but the —K culture. Sucrose is highest in the cane of the —Ca culture. Acid-hydrolyzable carbohydrates show little variation among the cultures.

5. The quality ratios of the —Mg, —B, and —Fe were very poor. In the other cultures, there were small variations. The correlation between the quality ratio and the total sugar level of the young sheaths, except for the —Fe culture, was very good.

6. The influences of the various deficiencies on the amounts of N, P, and K found in the various tissues are presented.

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Cane Growth Studies

Factors Which Influence Yields and Composition of Sugar Cane

By R. J. Borden

Our desire for facts concerned with the various influences which affect cane yields and its composition has been the motive for another study of the effects of climate, soil, varieties, and fertilization.

In 1936 we reported* a dominating effect of climate upon the growth and plant crop yields of three sugar cane varieties, each grown on two different soil types, and all duplicated under two distinctly different climatic environments. Subsequently we harvested four ratoon crops from these same plantings and secured verification for much of the data originally reported. Since these data have not been reported collectively, we offer them in summary form in the following tables, but before doing so we should like to present again briefly the plan and conditions under which these studies have been conducted.

The Plan: Two different climatic environments were used, with a duplicated plan installed at each location. At the Makiki station where the elevation is only 40 feet above sea level, bright sunny days with relatively few rainy days are the rule, whereas at the 650-foot elevation of the Manoa substation there are many rainy days and less than 50 per cent of the sunlight received at Makiki. Maximum temperatures at Makiki are about 4 degrees higher than at Manoa but there is not much difference in the minimum temperature. Table I shows the comparative weather conditions which have been measured while these studies were underway.

Semi-protection from heavy winds and generally adequate irrigation were supplied so that variations in these two factors would not become depressive growth-effect factors and complicate the interpretation of the results. Hence we were chiefly concerned with the effects of the environmental factors of sunlight and maximum temperatures.

TABLE I

COMPARATIVE WEATHER CONDITIONS FOR ACTUAL GROWING PERIODS OF CROPS

Crop	Total inches rainfall		No. of days with rain exceeding ½ inch		Mean minimum temperature		Mean maximum temperature		Total day-degrees	
	Makiki	Manoa	Makiki	Manoa	Makiki	Manoa	Makiki	Manoa	Makiki	Manoa
Plant—1935	47	199	20	99	67.5	67.4	84.6	80.2	6445	4488
1st ratoon—1936	44	182	21	110	68.1	66.6	83.0	77.8	4738	2959
2nd ratoon—1938	46	214	20	165	69.1	68.0	83.1	78.9	4942	3346
3rd ratoon—1939	39	197	18	122	69.7	67.3	82.8	78.8	4699	3394
4th ratoon—1940	38	173	10	113	63.2	60.9	82.9	78.9	4504	3428
Plant—1941	18	140	3	86	69.1	67.4	83.8	80.2	5321	3926

* Borden, R. J., 1936. Cane Growth Studies—The Dominating Effect of Climate, The Hawaiian Planters' Record, 40: 143–156.

Well-mixed soil from each of two sources placed in large 2′ x 2′ x 2′ concrete tubs provided the medium in which 3 cane varieties—H 109, Striped Tip, and POJ 2878—were originally planted in October 1934 at both locations. The Makiki soil, an alluvial chocolate-brown loam of fine structure, when wetted takes up water and also drains somewhat slowly, and packs quite firmly but without cracking as it dries. It has a slightly alkaline reaction and is well supplied with available phosphates, potash, and calcium; its content of organic matter is not high and its available nitrogen content is quite low. By contrast the Manoa soil, a residual yellow-brown silty loam, has an excellent granular structure that makes it porous and well drained. Its reaction is quite acid and its content of replaceable bases low. It is quite high in its organic matter content, contains a fair amount of available nitrogen, but has high phosphate-fixing properties; hence, to insure an adequate supply of phosphate in this Manoa soil, a heavy application of rock phosphate was mixed in under the seed before the original plantings were made.

All treatments were installed in triplicate, and analytical and yield data given hereafter include the measurements from all three tubs of each treatment. Adequate fertilization from ammonium sulphate, superphosphate, and muriate of potash was given frequently and similarly to all three varieties on both soils at each location. In addition, a supplementary series with POJ 2878 only was inadequately fertilized with only one fourth as much NPK as the adequately fertilized series received.

Five crops were harvested from the original plantings, as follows:

PROJECT A-105-NO. 43—CROPS HARVESTED

No.	Crop cycle	Year	Started	Harvested	Growing period
1	Plant crop	1935	Sept. 28, 1934	Dec. 14, 1935	442 days
2	1st ratoon	1936	Dec. 14, 1935	Dec. 16, 1936	368 "
3	2nd ratoon	1938	*April 9, 1937	April 22, 1938	376 "
4	3rd ratoon	1939	April 23, 1938	April 20, 1939	362 "
5	4th ratoon	1940	April 21, 1939	May 7, 1940	380 "

* Re-started after cutting back.

The Effects of Climate: The effects of climate are summarized in Table II; and discussed thereafter.

It is immediately apparent that the differences in climate have had definite effects. Cane Yields, quality (Y%C), and sugar yields have been consistently and considerably greater under the more favorable growing conditions at Makiki, and this generalization has apparently held true regardless of soil or cane variety, thus indicating the dominating effect of climate on yields.

The effect of climate on the percentage of phosphate in the crusher juices was not significant, but the canes grown at Manoa, regardless of soil, did have a significantly greater potash concentration than duplicates grown at Makiki.

It is doubtful whether the effect of climate on the pH of the soils at each harvest was significant, although it appeared for the first two crops that the soils cropped at Manoa had become more acid than duplicates at Makiki.

The data in Table II contain other items of interest. The higher yields from the plant crop are most likely due to the fact that it was two months older than the ratoons. The lower cane yields of the third and fourth ratoons may have been due

TABLE II

EFFECTS OF CLIMATE

Combined data from 3 replicates of 3 varieties, each grown in 2 soils, with adequate fertilization;
Average of 18 pots

Crop	Lbs. cane grown at		Y%C grown at		Lbs. sugar grown at		% P_2O_5 in juice grown at		% K_2O in juice grown at		pH of soil at harvest grown at	
	Makiki	Manoa	Makiki	Manoa	Makiki	Manoa	Makiki	Manoa	Makiki	Manoa	Makiki	Manoa
Plant—1935	77	30	11.7	8.6	8.9	2.7	.062	.071	.16	.21	5.8	5.4
1st ratoon—1936	73	24	10.2	7.8	7.5	1.9	.056	.055	.13	.17	5.8	5.3
2nd ratoon—1938	67	23	11.9	9.1	8.0	2.1	.064	.064	.10	.18	5.0	5.0
3rd ratoon—1939	63	23	9.8	8.4	6.2	1.9	.067	.073	.08	.15	5.1	5.2
4th ratoon—1940	66	21	12.1	9.4	8.1	2.0	.077	.081	.03	.11	4.8	4.5
Averages	69	24	11.1	8.7	7.8	2.1	.065	.069	.10	.16	5.3	5.1

TABLE III

EFFECTS OF SOIL

Combined data from 3 replicates of 3 varieties, each grown in 2 climates, with adequate fertilization;
Average of 18 pots

Crop	Lbs. cane Soil		Y%C Soil		Lbs. sugar Soil		% P_2O_5 in juice Soil		% K_2O in juice Soil		pH of soil at harvest* Soil	
	Makiki	Manoa	Makiki	Manoa	Makiki	Manoa	Makiki	Manoa	Makiki	Manoa	Makiki	Manoa
Plant—1935	47	60	10.6	9.7	5.4	6.3	.101	.032	.25	.12	6.1	5.1
1st ratoon—1936	45	53	9.3	8.7	4.8	4.9	.085	.025	.21	.09	6.4	4.7
2nd ratoon—1938	41	49	10.3	10.6	4.8	5.6	.093	.035	.17	.11	5.4	4.6
3rd ratoon—1939	37	49	9.1	9.1	3.5	4.7	.095	.045	.15	.08	5.5	4.8
4th ratoon—1940	38	49	10.6	10.9	4.3	5.8	.101	.057	.08	.06	4.8	4.5
Averages	42	52	10.0	9.8	4.5	5.4	.095	.039	.17	.09	5.6	4.7

* When the soils were originally potted the pH measurements were 7.2 for the Makiki soil and 5.4 for the Manoa soil.

to some rat damage at Manoa. However, it is not apparent that cane yields were seriously affected by continued cropping from potted soils, and certainly the sugar yields from the fourth ratoons were not significantly less than from previous ratoons grown at either Makiki or Manoa.

It would be interesting to know why the Y%C has been so variable from the second, third, and fourth ratoons which had approximately the same calendar growing periods, and which were apparently similarly influenced, *i.e.*, at both locations the 1939 crop had the lowest Y%C, the 1940 crop the best Y%C, with the 1938 crop Y%C figures being intermediate.

The per cent K_2O in the crusher juice shows a marked decrease in each successive crop at both locations. This decrease has occurred in spite of the fact that heavy potash fertilizer applications were made monthly on both soils throughout each cropping period. We have no satisfactory explanation for this decrease.

The effect of continued cropping also shows in the increased soil acidities that were measured.

The Effects of Soil: In Table III, we have summarized the effects of soil.

Although not as great as the effects of climate, it is interesting that the Manoa soil which has not been considered a "good" producing soil has consistently grown more cane and sugar than the Makiki soil. We believe this may be due to its superior physical characteristics which provide better aeration for root growth.

It is doubtful whether the cane quality (Y%C) has been influenced by the differences between the two soils which were used. In the first two harvests it was believed that the Makiki soil had produced cane with a better sugar content, but this was not verified in the subsequent three harvests.

There is no question, however, but that cane grown on the Makiki soil has had a higher concentration of both phosphate and potash in the crusher juices than that grown on Manoa soil, in spite of identical fertilization with phosphate and potash (except for the extra raw rock phosphate which was mixed into the Manoa soil before planting in 1934).

The Manoa soil has become still more acid than the Makiki soil; it shows a net loss of 275 acidity units* as compared with a net loss of 161 for the Makiki soil in less than 6 years. This is probably the effect of the heavy applications of ammonium sulphate which have been continued while the crops were growing. And yet apparently this increased acidity has not markedly reduced its ability to give satisfactory crops, for we do not find that comparable ratoons have given differences in sugar yields that are proved effects from soils which produced them.

The Effects of Varieties: Yields and crusher juice analyses from the three cane varieties which were studied are given in Table IV:

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*

Time	Makiki soil pH	Makiki soil Acidity units	Manoa soil pH	Manoa soil Acidity units
Before planting (1934)	7.2	+ 1.0	5.4	— 40
After 4th ratoon (1940)	4.8	— 160.0	4.5	— 315
Difference		— 161		— 275

TABLE IV

EFFECTS OF VARIETIES

Combined data from 3 replicates on 2 soils, each under 2 climates with adequate fertilization; Average of 12 pots

Crop	Lbs. cane			Y%C			Lbs. sugar			% P_2O_5 in juice			% K_2O in juice		
	H 109	Str. tip	POJ 2878	H 109	Str. tip	POJ 2878	H 109	Str. tip	POJ 2878	H 109	Str. tip	POJ 2878	H 109	Str. tip	POJ 2878
Plant	64	46	52	10.0	9.9	10.0	7.2	4.8	5.5	.049	.085	.058	.15	.18	.22
1st ratoon	57	45	44	7.8	9.9	9.2	5.0	4.8	4.3	.037	.079	.051	.12	.15	.18
2nd ratoon	51	38	46	10.2	10.2	11.0	5.7	4.1	5.5	.039	.097	.057	.11	.15	.16
3rd ratoon	53	31	45	8.9	9.1	9.2	4.9	2.9	4.4	.045	.104	.060	.08	.12	.14
4th ratoon	53	32	45	10.7	10.0	11.5	6.2	3.4	5.6	.045	.109	.083	.05	.08	.09
Averages	56	38	46	9.5	9.8	10.2	5.8	4.0	5.1	.043	.095	.062	.10	.14	.16

TABLE V

EFFECT OF ADEQUATE FERTILIZATION

Combined data from 3 replicates on 2 soils, each under 2 climates with variety POJ 2878 only; Average of 12 pots

Crop	Lbs. cane		Y%C		Lbs. sugar		% P_2O_5 in juice		% K_2O in juice		pH of soil at harvest	
	Adeq. fertilized	Inadeq. fertilized	Adeq. fertilized	Inadeq. fertilized	Adeq. fertilized	Inadeq. fertilized	Adeq. fertilized	Inadeq. fertilized	Adeq. fertilized	Inadeq. fertilized	Adeq. fertilized	Inadeq. fertilized
Plant	52	25	10.0	11.7	5.5	3.0	.058	.080	.22	.18	5.9	5.9
1st ratoon	44	23	9.2	10.8	4.3	2.6	.051	.064	.18	.18	5.5	6.2
2nd ratoon	46	26	11.0	10.0	5.5	2.7	.057	.062	.16	.16	5.0	5.7
3rd ratoon	45	21	9.2	8.5	4.4	1.9	.060	.066	.14	.13	5.1	5.8
4th ratoon	45	20	11.5	11.9	5.6	2.4	.083	.088	.09	.09	4.7	5.7
Averages	46	23	10.2	10.6	5.1	2.5	.062	.072	.16	.15	5.2	5.9

Regardless of soil or of environment, H 109 has been the best producer of cane and sugar, but there were several crops in which the sugar yields from POJ 2878 were not significantly poorer; this was due to the superior quality of the POJ 2878 canes. Apparently Striped Tip was outclassed in all but the first ratoon when the Striped Tip grown at Manoa was superior to POJ 2878; in this case the POJ 2878 had produced 60 per cent tasseled stalks as compared with only 16 per cent tassel in the Tip canes.

All three varieties differed in the percentage composition of their crusher juices. In all five crops that were harvested, the Striped Tip canes had significantly higher concentrations of phosphate, while the lowest concentrations were in the H 109. In the case of potash, H 109 was also lowest in per cent K_2O for all five crops, but POJ 2878 generally had a slightly greater concentration than Striped Tip.

Although not summarized in Table IV, pH data concerned with soils at harvest do not indicate that these varieties have had any differential effect upon the soil reaction.

The Effect of Inadequate Fertilization: At both Makiki and Manoa the variety POJ 2878 only was grown on both Makiki and Manoa soil with both an adequate and an inadequate supply of fertilizer, more especially of nitrogen. The results from this comparison are summarized in Table V.

Both cane and sugar yields were greatly reduced when the crop was inadequately fertilized; this was true regardless of the soil upon which it was grown or the environment in which it developed.

The effects of "inadequate" fertilization on the per cent P_2O_5 in the crusher juice need an explanation. This is believed to be due to the fact that the available nitrogen supply was greatly deficient, and in such cases plants are generally known to take up an excessive amount of phosphate; apparently there was sufficient available phosphate in these soils even though the amount subsequently applied for the "inadequate" series was only one fourth of that given to the adequately fertilized plants.

Other than in the plant crop, the per cent K_2O found in the crusher juices of the "inadequately" fertilized group was not significantly less than that found when the canes received 4 times as much in their monthly fertilizer applications. This finding is quite contrary to our previous experiences wherein we have measured a positive relationship between potash supplied and potash found in the juice. It may be that what we have considered "adequate potash fertilization" has actually been an insufficient amount for the large amount of leafy stalks grown in pots with a restricted root area; perhaps the juice K_2O analysis itself from these five crops suggests this explanation, for the per cent K_2O in both groups quite definitely falls off with each successive harvest.

The effect of the greater supply of fertilizer (largely ammonium sulphate) on the adequately fertilized series has been to give the soil a lower pH; soil acidity in the inadequately fertilized pots has not been materially affected by the fertilization.

Fig. 1. Variety H 109 (left to right)—(1) grown on Makiki soil at Ma` ·i (2) grown Iakiki soil at Manoa; (3) grown on Manoa soil at Makiki; (4) grown ınoa soil at oa. All with *adequate* fertilization.

Fig. 2. Variety 32–1063 (left to right)—(1) grown on Makiki soil at Makiki; (2) grown on Makiki soil at Manoa; (3) grown on Manoa soil at Makiki; (4) grown on Manoa soil at Manoa. All with *adequate* fertilization.

Fig. 3. Variety 32–8560 (left to right)—(1) grown on Makiki soil at Makiki; (2) grown on Makiki soil at Manoa; (3) grown on Manoa soil at Makiki; (4) grown on Manoa soil at Manoa. All with *adequate* fertilization.

Fig. 4. Variety 32–8560 (left to right)—(1) grown on Makiki soil at Makiki; (2) grown on Makiki soil at Manoa; (3) grown on Manoa soil at Makiki; (4) grown on Manoa soil at Manoa. All with *inadequate* fertilization.

Our Second Study*

Following the harvest of the 1940 crops from the test we have just discussed, it was decided to repeat the study on the same soils and at the same locations but to substitute two new cane varieties—32–1063 for the Striped Tip and 32–8560 for the POJ 2878—and to replant the H 109 in the same containers previously cropped to this variety. Otherwise the plan was to be identical with the previous installation, although a few additional analyses were to be included.

After harvesting, the old stubble was immediately dug out, the upper foot of soil in each container was turned up, and subsequently the roots and all but the coarser parts of the stubble were returned and thoroughly mixed into the soil; this provided a large supply of organic matter from the old cane root systems. During the next six weeks, the soils were kept moist and turned over twice to assist the decay of the organic matter. The new seed was planted on June 18, 1940. Superphosphate solution was uniformly applied under the seed pieces, and thereafter the original plan was duplicated.

The 1941 crop was harvested at the age of 386 days on July 9, 1941, and photographs of cane from a representative pot of each treatment were made a matter of record. These are shown as Figs. 1 to 4.

To assist in a correct interpretation of the results from this plant crop the data have been set up for statistical studies and an analysis to show both the main effects and their interactions. In Part A, we have a study of a 2 x 2 x 3 factorial plan in which 2 climate, 2 soil, and 3 variety influences have been operative under adequate fertilization. In Part B, a 2 x 2 x 2 factorial arrangement provides a study of 2 climates, 2 soils, and 2 levels of fertilization for the variety 32–8560 only.

Part A: The analysis of variance for Part A appears in Table VI; the summaries of harvest data are given in the Appendix.

TABLE VI

ANALYSIS OF VARIANCE

Part *A*—2 × 2 × 3 Factorial—*2 Climates* × *2 Soils* × *3 Varieties*
(All with adequate fertilization)

Source	D. F.	Mean squares or variances for— cane	purity	Y%C	sugar
Climate (C)	1	24,211.36†	4.84	27.7378†	366.78†
Soil (S)	1	1,487.39†	13.93	9.3636*	45.72†
Variety (V)	2	574.68†	36.56*	17.6112†	22.86†
C × S	1	920.11†	59.29*	7.8400*	32.93†
C × V	2	3.42	6.77	2.0175	4.53
S × V	2	88.68	4.94	3.1076	4.80
C × S × V	2	26.21	7.57	1.7376	1.40
Error	24	77.69	9.31	1.3304	1.74
Total	35				
Mean		48.68	85.72	10.30	5.38
C. V.		18.09%	3.56%	10.73%	24.54%

* Project A-105-No. 43.1—1941 crop.

Source	D. F.	Mean squares or variances for % N in juice	% P_2O_5 in juice	% K_2O in juice	% N in soil	pH of soil
Climate (C)	1	.000685†	.000097	.0765†	.0003	.84†
Soil (S)	1	.000667†	.014844†	.0659†	.0592†	10.56†
Variety (V)	2	.001561†	.005264†	.0178†	.0028*	.005
C × S	1	.001980†	.000392	.0011	.0064†	0
C × V	2	.000232*	.000308	.0042*	.0033*	0
S × V	2	.000062	.001360*	.0078†	.0010	.025*
C × S × V	2	.000106	.000022	.0011	.0026*	.005
Error	24	.000066	.000271	.0010	.0006	.0067
Total	35					
Mean		.030	.058	.16	.001400	5.2
C. V.		27.0%	28.37%	19.75%	17.5%	1.58%

* Favorable significance. † High significance.

Discussion of Results (Part A):

Effects of Climate: The dominating independent effect of climate upon sugar cane yields from different varieties has again been demonstrated, with Makiki producing more than three times the amount of millable cane than Manoa in a period of 12½ months. At the same time all canes grown at Makiki were superior in their quality, with the result that the Makiki sugar yields were almost four times those produced at Manoa.

An influence of climate was also found on the pH of the soil after harvest, on the percentage of potash in the crusher juices, and on the percentage of nitrogen in the juices, although this latter effect was modified by the soil upon which the cane was grown and by the cane variety. Apparently neither the phosphate content of the crusher juices, nor the available nitrogen remaining in the soil at harvest were affected by climate.

Whereas natural rainfall furnished the greater part of the irrigation water needed at Manoa, it was necessary to use considerably more and a slightly alkaline tap water at Makiki; hence this fact may account for the less acid condition in which the soils cropped at Makiki were left after harvest.

The per cent potash in the crusher juice of all three varieties was definitely higher when they were grown at Manoa. This fact verifies a similar result that we previously secured and indicates a rather significant effect from a difference in climate.

The effect of climate on the percentage of nitrogen in the crusher juices was quite definitely modified by the soil upon which the cane was grown and also by the variety. With the Makiki soil, the nitrogen content of the crusher juices was definitely higher under the conditions at Makiki than at Manoa, whereas with the Manoa soil we have no reliable proof that the climatic effects were different and, perhaps, even an indication that there was a lower percentage of N in the canes grown at Makiki on this soil. The variety 32–8560 had a definitely higher per cent N in its juice at Manoa than either 32–1063 or H 109, but at Makiki the per cent N difference between 32–8560 and 32–1063 was not significant.

Although the heavier yielding cane crops produced at Makiki on the Manoa soil had a better juice purity than the lower cane yields that were grown at Manoa,

no significant influence of climate was measured on crusher juice purity when the Makiki soil was used.

Effects of Soil: Several soil effects were found to be quite independent of interactions with either climate or variety. Thus the percentages of P_2O_5 and of K_2O in the crusher juices, as well as the pH and the available nitrogen content of the soils after harvest are believed to be real soil influences.

The Makiki soil has produced cane with considerably greater concentrations of mineral plant nutrients than the Manoa soil, and it has remained less acid in its reaction also. On the other hand the Manoa soil held a greater reserve of available nitrogen at harvest.

Other soil effects have been somewhat modified by their interactions; for instance, climatic influences have altered the soil effects on cane yields. Thus, although the Manoa soil produced more cane than the Makiki soil when cropped at Makiki, there was no proved differences in cane yield between the two soils when they were cropped at Manoa.

Cane purities and yield per cent cane were significantly better from the Manoa soil when it was cropped at Makiki, but under the Manoa environment the effect of soil on these indices of juice quality may have been even just the opposite.

As was noted for the cane yields, the sugar yields from these two soils have been differently influenced by climate, i.e., a significant increase in sugar was obtained from the Manoa soil at Makiki, but no real difference in sugar was measured between the soils when cropped at Manoa.

We also note that although the per cent N in the crusher juice of canes grown on Makiki soil at Makiki was higher than that in cane on Manoa soil at the same place, it appears that the reverse effect was quite likely secured from these same comparisons at Manoa.

Finally, it is of interest to compare the average soil acidities or pH values found in these two soils after this 1941 plant crop harvest and in the same containers following their 1940 fourth ratoons.

Soil	pH at 1940 harvest	pH at 1941 harvest
Makiki	4.8	5.7
Manoa	4.5	4.7

Since there was no evidence of an interaction between soil and climate on the pH of the soil at harvest, one may only speculate as to the real reason for this evidence of decreased soil acidity in these soils.

Effect of Varieties: Yield and quality effects from the three cane varieties were not differentially influenced by climate or soil factors. Both 32–8560 and 32–1063 produced more cane than H 109 but the difference between them was not significant; however, the superior cane quality of 32–8560 gave it a significant lead in sugar yield over 32–1063. Similarly we note a variety influence on the per cent N in the crusher juice which is apparently quite independent of other factors studied: H 109 has a much lower concentration of N than 32–1063, while 32–8560 carries a significantly greater percentage.

The variety influence on both per cent P_2O_5 and per cent K_2O in the crusher juice is apparently modified by the soil factor. For instance, 32–8560 has a much higher percentage of P_2O_5 than the other two varieties on the Makiki soil, but

not more than 32–1063 on the Manoa soil. And whereas both 32–8560 and 32–1063 have a greater concentration of K_2O in their juices than H 109 when grown on Makiki soil, there was no real per cent K_2O difference between these three varieties when they were grown on the Manoa soil.

Climate has also modified the variety effect on the per cent K_2O in the juices: 32–8560 had a higher per cent K_2O than 32–1063 when it was grown at Manoa, but at Makiki its crusher juice carried a lower concentration than 32–1063.

The per cent N in the soil at harvest showed the result of a variety x climate interaction also, i.e., H 109 left more available nitrogen in the soil at Makiki than either of the other varieties, whereas at Manoa no real differences were measured as variety effects on this soil nitrogen content.

A differential variety influence on the soil pH may also be indicated as a combined influence of the soil. On the Makiki soil, 32–8560 has apparently left a less acid condition at harvest, but on the Manoa soil this cane variety has increased the soil acidity over that planted to H 109 or 32–1063.

Part B: The analysis of variance for Part B of this study is given in Table VII; the summaries of the harvest data are given in the Appendix.

TABLE VII

ANALYSIS OF VARIANCE

Part *B*—2 × 2 × 2 Factorial—*2 Climates × 2 Soils × 2 Levels of Fertilization*

(Variety 32–8560)

Source	D. F.	Mean squares or variances for cane	purity	Y%C	sugar
Climate (C)	1	9,381.26†	12.18*	28.6454†	213.9648†
Soil (S)	1	654.17†	1.98	2.7473*	21.8122†
Fertilizer (F)	1	2,295.17†	101.27†	17.8538†	23.5224†
C × S	1	160.61†	43.47†	6.8054†	12.3841†
C × F	1	911.43†	.08	.3651	16.4672†
S × F	1	439.47†	13.36*	2.1243	14.9468†
C × S × F	1	133.95*	17.50*	3.1389*	9.2505†
Error	16	16.70	2.64	.5302	.4524
Total	23				
Mean		44.6	89.7	12.54	5.79
C. V.		9.16%	1.81%	5.81%	11.62%

Source	D. F.	Mean squares or variances for % N in juice	% K_2O_5 in juice	% K_2O in juice	% N in soil	pH in soil
Climate (C)	1	.000048	.000260	.0477†	.00000002	2.10†
Soil (S)	1	.000204†	.022143†	.0852†	.00000322†	5.13†
Fertilizer (F)	1	.004873†	.000532	.0155†	.00000073†	1.26†
C × S	1	.000542†	.001081*	.0035	.00000025*	.40†
C × F	1	.000141†	.000126	.0109*	.00000002	.45†
S × F	1	.000369†	.000093	.0004	.00000014	.40†
C × S × F	1	.000792†	.000220	.0014	.00000020*	.36†
Error	16	.000013	.000157	.0013	.00000004	.004
Total	23					
Mean		.026	.073	.016	.0012	5.5
C. V.		13.85%	17.12%	22.50%	16.67%	1.15%

* Favorable significance. † High significance.

Discussion of Results (Part B):

Effect of Climate: The effect of climate is again shown to be the dominant factor for 32–8560 cane and sugar yields, and also for yield per cent cane; thus Makiki again provided the more desirable climatic influences. The same differential effect of climate on juice purity was again measured; for instance, when grown on Manoa soil, the 32–8560 cane at Makiki had a significantly higher purity than duplicates grown at Manoa, but on the Makiki soil this result was not found to have been influenced by the difference in environment.

The percentages of nitrogen and of phosphate in the crusher juices were not directly influenced by the different climates, but there is evidence that climatic conditions did alter the effects upon these juice constituents which came from the differences in soils and fertilizers. For instance, although the per cent N in the juice of cane grown on Makiki soil was higher when grown at Makiki than at Manoa, this differential effect was just the reverse on the Manoa soil. Furthermore, these effects were also influenced by the fertilizer which was supplied, i.e., with adequate fertilization the foregoing statements are correct, but when an inadequate amount of fertilizer (especially nitrogen) was furnished, this interaction between climate and soil was not sufficiently effective to give any real difference in the per cent N of the juice. The per cent P_2O_5 in the juice of canes grown on Makiki soil at Manoa was higher than on this same soil at Makiki, but on the Manoa soil there was no reliable climatic effect on phosphate concentration.

There is evidence of a significant effect of climate on the per cent K_2O of the crusher juice with the cane grown at Manoa again having the higher concentration of this nutrient.

Apparently climate has played a very minor role to both soil and fertilizer in influencing the available nitrogen content of the soil at harvest. The Manoa soil has the greater per cent N at harvest regardless of climate or fertilization, and although an interaction between climate and soil is found under conditions of adequate fertilization, a similar interaction under inadequate fertilization is not identified. This will be more fully discussed under "Effect of Fertilizers."

The pH of the soil at harvest is again less acid under Makiki than under Manoa climatic influences, and this effect is apparently not changed by soil or fertilization. It may, however, be the result from using a slightly alkaline tap water (pH 7.1) for the irrigation which is necessary at Makiki.

Effect of Soil: Independent effects of soil upon the percentages of P_2O_5 and K_2O in the crusher juice, and upon the available nitrogen content and pH of soil at harvest are again indicated. The Makiki soil has produced canes with very much higher concentrations of both phosphate and potash in their juices, and at harvest was still less acid than the Manoa soil; the Manoa soil had a higher percentage of available nitrogen at harvest.

The effect of soil upon the cane yields was differentially influenced by other factors. The Manoa soil produced more cane than the Makiki soil when both soils were cropped at Makiki, but the differences were not highly significant when they were both cropped at Manoa. Furthermore, these results were obtained only when the canes were adequately fertilized, for with inadequate fertilization these cane yield differences were not proved effects of soils.

The effect of soil upon juice purity has been regulated by the difference in climate and also by the fertilization. At Makiki, the Manoa soil produced a higher purity cane than the Makiki soil when both were adequately fertilized, but with this same adequate fertilization at Manoa, the Makiki soil produced cane with the higher purity. With inadequate fertilization, however, there were no differences in purity which could be attributed to soil effects at either location.

Differential effects were also found upon the Y%C, i.e., (a) a higher recovery of sugar from cane grown on Manoa soil at Makiki under adequate fertilization, but not from Manoa soil grown at Manoa, and (b) no significant soil effects on the Y%C at either location when the fertilization was inadequate.

Sugar yields were in general higher from the Manoa soil; however, here too, we have evidence of influences by both climate and fertilization which necessitate a modification of this generalization. Thus, although the Manoa soil produced a higher sugar yield when given adequate fertilizer and cropped at Makiki than did the Makiki soil, this was the only condition where this superiority of the Manoa soil was positively established; when cropped at Manoa, with either adequate or inadequate fertilizer, the Manoa soil was not proved a better sugar producer than the Makiki soil.

And finally, the effect of soil upon the per cent N found in the crusher juice of 32–8560 was also influenced by both climate and fertilizer. Inadequately fertilized cane produced crusher juices which were apparently not influenced by either the soil or the climate where they were grown. But when cane received ample fertilizer at Makiki, the Makiki soil put a considerably higher concentration of N in the juice than the Manoa soil did, whereas an opposite effect from these two soils on per cent N in juice was found when the crop was grown at Manoa.

Effect of Fertilizer: The effects of the differences in the fertilization of this 32–8560 cane, i.e., an adequate amount vs. one fourth as much or an inadequate amount, especially of nitrogen, upon its juice purity, Y%C, per cent N in juice, and per cent N in soil at harvest are apparently not greatly changed by differences in climate or in soil. Thus a better purity, and a higher yield of recoverable sugar came from the cane which received the smaller amount of fertilizer, whereas the per cent N in the crusher juice and the per cent N left in the soil at harvest were higher from the more adequately fertilized crop.

The influence of fertilizer on the cane and sugar yields was modified by both climate and soil, especially by the former. With regard to cane, greater yields were secured from adequate fertilization at Makiki on both soils, but at Manoa, although the Manoa soil responded to the adequate fertilization, there was no reliable similar gain from the Makiki soil. Regarding sugar, we find another interesting second-order interaction, viz., adequate fertilization produced more sugar than limited fertilization when applied to Manoa soil at Makiki but on the Makiki soil this gain was not significant; furthermore, this adequate fertilization on Makiki soil was not proved more effective than inadequate fertilization when the cane was cropped either at Makiki or at Manoa.

Our differences in fertilization apparently have had no very great effect on the per cent P_2O_5 of the crusher juices. The average percentages as found (.068–.078) are considered very high and perhaps the total initial phosphate sup-

plies were so generous that subsequent differences in amounts of phosphate fertilizer applied were comparatively ineffective.

The effect of fertilizer on the per cent K_2O of the crusher juice was definitely influenced by the differences in climate. Whereas the cane grown at Makiki was not influenced, cane at Manoa which had been adequately fertilized carried a much higher per cent K_2O in its crusher juice than cane at Manoa which was less adequately supplied with fertilizer carrying potash.

The pH of the soil at harvest was influenced by the fertilizer which had been applied, but there were differences in fertilizer effects which can be traced to interactions with the effects of both climate and soil. Thus the pH of the Makiki soil when cropped at Manoa has not been significantly changed by the differences in fertilization; whereas the lower pH of this same soil at Makiki indicates an effect from the more adequate fertilization, with its large amounts of N from ammonium sulphate. The differences in acidity of the Manoa soil are quite definite effects from the fertilizations: the differences in pH is slightly larger at Makiki than at Manoa.

Summary: Once again we have quite clearly measured the dominating effects which climate exerts upon yields and composition of sugar cane. There are also definite soil effects, variety effects, and fertilizer effects, but many of these are also influenced or modified by differences in climate. Hence it is quite gratifying that we have been able to identify some of the interactions between these various factors which can affect the cane crop, and thereby secure a better understanding of both their independent and interlocking effects for guidance in growing sugar cane.

Considering the two different environments tested in these studies, it is apparent that sugar yields at Manoa can only be one third to one fourth of the yields which can be obtained at Makiki; hence we need not waste much time attempting to increase them beyond this proportion, for the climatic factors at Manoa are not favorable for greater sugar yields, even when adequate water and food are supplied, soil conditions are greatly altered, or good varieties are planted.

Some characteristic of soils other than their moisture and available nutrient content can influence sugar yields, especially when climatic influences are conducive to heavy cane yields. But when the climate limits the cane yields to low tonnages, the influence of this soil factor is not significant. It is our belief that the specific characteristic which makes one well-fertilized soil superior to another, is its better physical condition. Hence our attention to securing an improved physical condition of soils in regions where heavy cane tonnages can be grown should take precedence over similar soil improvement operations in regions where yields will be lower, for returns from the former should be considerably greater.

Speaking only for the few cane varieties which were studied, and considering only their comparative sugar yields, it would appear that the superior yielding variety was superior, regardless of the soil on which it was grown or of the climatic conditions under which it made and stored its sugar, providing it had received adequate food and water. Thus for the range in climatic conditions between Makiki and Manoa, a need for variety differentiation is not indicated if final sugar yield is the only criterion for preference. (Unfortunately, data to

estimate profits from these sugar yields are not available, and it is not unlikely that the costs of production will be quite different.)

Of all four factors studied, the effect on sugar yields which comes from fertilizer is the most completely tied up with complementary effects from soil and climate. Apparently there is little to be gained from increased fertilization under low sunlight conditions such as are found at Manoa, *i.e.*, piling on the fertilizer will not give increases in sugar under such climatic influences. Similarly, increasing the fertilizer for a soil with an inferior physical condition has little effect upon the sugar yields, whereas a similar increase on a soil with superior physical characteristics does pay handsomely in larger crops of sugar.

The influence of any one of these four factors upon the percentage composition of the crusher juices is in some cases independent of, and in other instances dependent on some other factor. (This may be a reason why we have found it difficult to interpret many crusher juice analyses.) For instance: although the effect from different soils upon the per cent P_2O_5 and per cent K_2O of crusher juices is apparently independent of other factors, this is not the case upon the per cent N, for both a difference in climate and in fertilizer have modified the effect of soil upon the nitrogen concentration. Similarly, although a variety influence upon the per cent N in crusher juices is found to be independent of soil or climate, this same direct influence on the per cent K_2O in juice was not found when the varieties were grown on different soils or under different environments. And although a difference in fertilizer resulted in a corresponding difference in the per cent N of crusher juices, regardless of soil or climate, the fertilizer's effect on per cent K_2O was not the same when used under different climatic conditions.

Soil effects on the nitrogen content and pH of soil at harvest were quite definite and not influenced by other factors. Climate had an independent effect upon the pH; also a direct effect from the difference in fertilization was measured on the per cent N in soil at harvest. However, the variety effects on these two soil measurements were not always the same: (a) under different climates, variety effects on per cent N were influenced by differences in climate; and (b) on different soils the variety effects on soil pH were somewhat modified.

The complexity of effects produced on sugar cane by only these four factors—climate, soil, variety, and fertilizer, both separately and by their interactions—is apparent from the results that have been measured and recorded. Undoubtedly the picture is still more complex when other growth factors are involved. All of this sums up to the fact that attempts to allocate many of the possible cause and effect relationships to specific growth factors may be quite unsatisfactory, because of the many other non-identified conditions which can be involved when sugar cane is grown in the field.

Appendix

Part A—Summary of Harvest Data

Main Effects

1. *Effects of Climate* (Average of 18 Replicates)

Measurement	Crop grown at Makiki	Crop grown at Manoa	Minimum difference required for significance
Cane (lbs.)	74.6	22.8	6.1
Purity	86.1	85.4	ns
Y%C	11.18	9.42	.79
Sugar (lbs.)	8.57	2.19	.91
% N in crusher juice	.034	.025	.006
% P_2O_5 in crusher juice	.056	.060	ns
% K_2O in crusher juice	.11	.20	.02
% N* in soil at harvest	.0015	.0014	ns
pH of soil at harvest	5.4	5.0	.06

2. *Effects of Soils* (Average of 18 Replicates)

Measurement	On Makiki soil	On Manoa soil	Minimum difference required for significance
Cane (lbs.)	42.3	55.1	6.1
Purity	85.1	86.3	ns
Y%C	9.79	10.81	.79
Sugar (lbs.)	4.25	6.51	.91
% N in crusher juice	.034	.026	.006
% P_2O_5 in crusher juice	.078	.038	.011
% K_2O in crusher juice	.20	.12	.02
% N* in soil at harvest	.0011	.0019	.0002
pH of soil at harvest	5.7	4.7	.06

3. *Effects of Varieties* (Average of 12 Replicates)

Measurement	H 109	32–8560	32–1063	Minimum difference required for significance
Cane (lbs.)	41.0	54.4	50.7	7.4
Purity	84.3	87.7	85.2	2.6
Y%C	9.40	11.68	9.83	.95
Sugar (lbs.)	4.02	6.78	5.34	1.11
% N in crusher juice	.018	.040	.032	.007
% P_2O_5 in crusher juice	.036	.078	.061	.014
% K_2O in crusher juice	.11	.18	.18	.03
% N* in soil at harvest	.0016	.0013	.0014	.0002
pH of soil at harvest	5.2	5.2	5.2	ns

* Water soluble N only. ns = not significant.

Significant Interactions

4. *Between Climate and Soils* (Average of 9 Replicates)

Measurement	Climate	On Makiki soil	On Manoa soil	Minimum difference required for significance
Cane (lbs.)	At Makiki	63.1	86.1	
	At Manoa	21.4	24.1	8.6
Purity	At Makiki	84.2	88.0	
	At Manoa	86.0	84.7	3.0
Y%C	At Makiki	10.20	12.16	
	At Manoa	9.38	9.47	1.12
Sugar (lbs.)	At Makiki	6.49	10.65	
	At Manoa	2.02	2.36	1.28
% N in juice	At Makiki	.046	.022	
	At Manoa	.022	.029	.008
% N in soil	At Makiki	.0010	.0020	
	At Manoa	.0012	.0017	.0003

5. *Between Climate and Varieties* (Average of 6 Replicates)

Measurement	Climate	Variety H 109	Variety 32–8560	Variety 32–1063	Minimum difference required for significance
% N in juice	At Makiki	.018	.044	.041	
	At Manoa	.017	.036	.023	.010
% K_2O in juice	At Makiki	.07	.12	.15	
	At Manoa	.16	.25	.21	.04
% N in soil	At Makiki	.0018	.0013	.0013	
	At Manoa	.0014	.0014	.0016	.0003

6. *Between Soils and Varieties* (Average of 6 Replicates)

Measurement	Soil	Variety H 109	Variety 32–8560	Variety 32–1063	Minimum difference required for significance
% P_2O_5 in juice	Makiki	.052	.110	.073	
	Manoa	.020	.045	.048	.020
% K_2O in juice	Makiki	.13	.24	.24	
	Manoa	.10	.12	.12	.04
pH of soil	Makiki	5.7	5.8	5.7	
	Manoa	4.7	4.6	4.7	.10

Part B—Summary of Harvest Data

Main Effects

1. *Effects of Climate* (Average of 12 Replicates)

Measurement	Crop grown at Makiki	Crop grown at Manoa	Minimum difference required for significance
Cane (lbs.)	64.4	24.8	3.5
Purity	90.4	89.0	1.4
Y%C	13.63	11.45	.63
Sugar (lbs.)	8.77	2.80	.58
% N in juice	.027	.024	ns
% P_2O_5 in juice	.070	.076	ns
% K_2O in juice	.11	.20	.03
% N in soil at harvest	.0011	.0012	ns
pH of soil at harvest	5.8	5.2	.06

2. *Effects of Soils* (Average of 12 Replicates)

Measurement	On Makiki soil	On Manoa soil	Minimum difference required for significance
Cane (lbs.)	39.4	49.8	3.5
Purity	89.4	90.0	ns
Y%C	12.20	12.88	.63
Sugar (lbs.)	4.83	6.74	.58
% N in juice	.029	.023	.003
% P_2O_5 in juice	.103	.043	.011
% K_2O in juice	.22	.10	.03
% N in soil at harvest	.0008	.0015	.0002
pH of soil at harvest	5.9	5.0	.06

3. *Effect of Fertilizer* (Average of 12 Replicates)

Measurement	With adequate fertilizer	With inadequate fertilizer	Minimum difference required for significance
Cane (lbs.)	54.4	34.8	3.5
Purity	87.7	91.8	1.4
Y%C	11.68	13.40	.63
Sugar (lbs.)	6.78	4.80	.58
% N in juice	.040	.012	.003
% P_2O_5 in juice	.078	.068	ns
% K_2O in juice	.18	.13	.03
% N in soil at harvest	.0013	.0010	.0002
pH of soil at harvest	5.2	5.7	.06

Significant First-Order Interactions

4. *Between Climate and Soils* (Average of 6 Replicates)

Measurement	Climate	On Makiki soil	On Manoa soil	Minimum difference required for significance
Cane (lbs.)	At Makiki	56.6	72.2	
	At Manoa	22.2	27.5	5.0
Purity	At Makiki	88.8	92.1	
	At Manoa	90.1	88.0	2.0
Y%C	At Makiki	12.76	14.50	
	At Manoa	11.64	11.25	.87
Sugar (lbs.)	At Makiki	7.10	10.44	
	At Manoa	2.57	3.04	.82
% N in juice	At Makiki	.035	.020	
	At Manoa	.025	.026	.004
% P_2O_5 in juice	At Makiki	.093	.046	
	At Manoa	.113	.039	.015
% N in soil	At Makiki	.0007	.0016	
	At Manoa	.0009	.0015	.0003
pH of soil	At Makiki	6.1	5.4	
	At Manoa	5.8	4.6	.08

5. *Between Climate and Fertilizer* (Average of 6 Replicates)

Measurement	Climate	With adequate fertilizer	With inadequate fertilizer	Minimum difference required for significance
Cane (lbs.)	At Makiki	80.3	48.0	
	At Manoa	28.4	21.2	5.0
Sugar (lbs.)	At Makiki	10.59	6.96	
	At Manoa	2.96	2.64	.82
% N in juice	At Makiki	.044	.011	
	At Manoa	.036	.013	.004
% K_2O in juice	At Makiki	.12	.11	
	At Manoa	.25	.15	.04
pH of soil	At Makiki	5.4	6.1	
	At Manoa	5.1	5.2	.08

6. *Between Soil and Fertilizer* (Average of 6 Replicates)

Measurement	Soil	With adequate fertilizer	With inadequate fertilizer	Minimum difference required for significance
Cane (lbs.)	Makiki	44.9	33.9	
	Manoa	63.9	35.8	5.0
Purity	Makiki	86.6	92.2	
	Manoa	88.7	91.3	2.00
Sugar (lbs.)	Makiki	5.04	4.63	
	Manoa	8.52	4.96	.82
% N in juice	Makiki	.047	.011	
	Manoa	.033	.013	.004
pH of soil	Makiki	5.8	6.0	
	Manoa	4.6	5.4	.08

Significant Second-Order Interactions

7. *Between Climate and Soil and Fertilizer* (Average of 3 Replicates)

Measurement	Climate	With adequate fertilizer: On Makiki soil	With adequate fertilizer: On Manoa soil	With inadequate fertilizer: On Makiki soil	With inadequate fertilizer: On Manoa soil	Minimum difference required for significance
Cane (lbs.)	At Makiki	65.9	94.8	47.3	49.6	
	At Manoa	23.9	33.0	20.5	21.9	7.1
Purity	At Makiki	85.2	91.7	92.4	92.5	
	At Manoa	88.1	85.7	92.1	90.2	2.8
Y%C	At Makiki	11.36	14.42	14.16	14.58	
	At Manoa	10.72	10.20	12.56	12.30	1.27
Sugar (lbs.)	At Makiki	7.51	13.67	6.69	7.22	
	At Manoa	2.56	3.37	2.57	2.71	1.16
% N in juice	At Makiki	.061	.027	.009	.013	
	At Manoa	.033	.040	.013	.013	.006
% N in soil	At Makiki	.0007	.0020	.0006	.0012	
	At Manoa	.0011	.0016	.0008	.0013	.0004
pH of soil	At Makiki	6.0	4.8	6.2	6.0	
	At Manoa	5.7	4.5	5.8	4.7	.11

Soil and Plant Material Analyses by Rapid Chemical Methods—III

By Francis E. Hance

CONTENTS

FOREWORD

Following the development of R.C.M. (Rapid Chemical Methods of Analysis) at this Experiment Station in 1932 (1), a normal expansion of the general scheme has occurred (2) and widespread adoption of this or similarly and independently developed methods have taken place in various agricultural regions throughout the world.

R.C.M. apparently has served a useful purpose and will continue to develop and expand. However, it is not endowed with infallibility nor can it boast of freedom from certain inherent limitations which, fortunately in most cases, may be subject to correction or practical modification without sacrifice of its essential characteristics of simplicity and rapidity of analytical accomplishment.

The present discussion presents detailed suggestions along lines of refinement and modification of R.C.M. on the basis of ten years of experience, both by ourselves and by workers in other countries with whom we have maintained contact in person or by correspondence.

New methods of analyses will be described. Particular attention will be given to the elucidation of obscure details in the earlier papers which have shown a need for clarification.

THE CLARIFICATION OF POINTS WHICH HAVE BEEN FOUND TO CAUSE A CERTAIN AMOUNT OF CONFUSION IN THE ORIGINAL PUBLICATION ("SOIL AND PLANT MATERIAL ANALYSES BY RAPID CHEMICAL METHODS"—THE HAWAIIAN PLANTERS' RECORD, 40: 189–299, 1936, AND AGRICULTURAL AND CHEMICAL SERIES BULLETIN NO. 50).

Reagent No. 1, K_2O:

On page 236: 500 grams of C.P. sodium acetate should be corrected to read 5000 grams.

The Potash Determination:

The Potash Rotator (pages 203–207): No changes have been found necessary or desirable in the construction or operation of this instrument. Of the several hundred which have been manufactured in Honolulu and put in service during the past ten years, none has broken down, to the best of our knowledge, but about five instruments have been worn out by extensive and hard usage.

Maximum wear on the rotator occurs along the point of contact between the brass spindle and the wooden rotor. As originally designed, the provision of a

metal bushing for the rotor was discarded because it was felt that lubrication would be neglected by some users and as a consequence the instrument would soon develop a rasp-like squeak. As a substitute the hardwood rotor was impregnated with grease along its centrally located shaft opening. Long usage enlarges this opening and wobbling develops. The condition is not serious and may be corrected by replacing the old rotor with a turned replica. The rubber tire on the rotor consists of nothing more than a very wide rubber band. A long sleeve or tube of thin rubber having about the following specifications may be purchased from chemical supply houses: Gooch rubber tubing, 1½″ diameter. Sections may be cut from the sleeve as required and placed on the rotor.

Note: Always remove the rotor from the spindle before attempting to apply the rubber tire. Unless this precaution is observed the spindle may be bent out of line and thus rendered considerably less effective.

The upper cover of the rotator should be removed about once or twice a year and the motor, bearings and governor assembly should be oiled with a good quality thin oil. Calibration of the speed of the rotator is important, but when proper adjustment is once made its maintenance is a minor problem because the rotator operates on 60-cycle alternating current through an induction motor. However, it is desirable to check speed of rotation at the time of oiling and, if necessary, to adjust the arm of the braking mechanism to bring the movement to exactly 78 r.p.m.

The Potash Vials: Short-form shell vials are specified in Bulletin 50. We have found it necessary to discard vials which have become scratched by repeated washings. They may be purchased at small cost from supply dealers. These vials should measure about 17.5 mm. outside diameter, 15.5 mm. inside diameter and 60 mm. in length. When a supply of vials is received, it will likely develop that the inside diameters vary to such an extent that the height of a measured 1 ml. of liquid in a series may be lengthened or shortened sufficiently from tube to tube to throw off the accuracy of comparable turbidimetric readings when using the vials by random selection. Accordingly, it has been found advantageous to prepare a turned wooden cylinder just large enough in diameter to fit snugly into a vial of correct inside diameter. (A 9/16″ wood dowel may do.) Using the prepared cylinder as a gauge, several gross of the vials may be tested and those found larger or smaller than the gauge may be reboxed and returned to the dealer for credit or exchange. As a rule the dealer will not object to accepting the odd vials because the variability in diameter is of little consequence to the average user. To register a carton of your own rejects on your dealer's shelves it is a good idea to place a small circle with a cross in it on the bottom of each carton you return. On future orders specify new goods, or explain the significance of your reject markings.

The True Values of R.C.M. Potash Findings for Soils and Crusher Juice:

R.C.M. Potash in Soil: By referring to Bulletin 50 one may observe that the soil potash procedure was perfected through a series of experimental trials, adjustments and refinements. Furthermore, it was essential to develop the method in such a manner that the transition from "kit" determination to the more precise R.C.M. could take place without sacrificing or adjusting the quite extensive com-

pilation of "kit" figures which were already on file. Still further it should be realized that two of the important objectives sought in the new procedure were to devise mechanical aides which would standardize the shaking operation in the analysis and provide a means of determining the extent of turbidity produced in the test (a direct index of potash content) under uniform conditions of illumination and arrangement of equipment. All these modifications were required to be calibrated in terms which would be directly comparable and equivalent to current data produced with identical soil specimens by an expert "kit" analyst.

Consequently, R.C.M. soil potash data were deliberately (but unfortunately) made to match as closely as we possibly could the general run of values turned out by a first-class kit operator on any given series of soil specimens. Later, research studies on the R.C.M. procedure revealed the fact that, on the average, R.C.M. soil potash figures, as given in the tables accompanying the method, represent the true percentages of potash extracted from the soil *times* the factor 0.4. Thus, standard R.C.M. values are two fifths of the actual concentration of K_2O extracted from the soil.

R.C.M. Potash in Crusher Juice or Plant Sap: The development of this procedure was made to meet a specified need. There was no necessity for introducing modifications to make the method level off to the values of another. Therefore the table accompanying this method is based on the actual amounts of potash which are present in the specimen.

A Factor For Conversion of R.C.M. Soil Potash Figures to Approximately Comparable Replaceable Potash Values:

Multiply the R.C.M. percentage value as shown in the R.C.M. table by 3.3. This factor was determined entirely by empirical means and represents an average of several thousand analytical comparisons. No established reliability is claimed for it.

The Preparation of R.C.M. Reagents

The exact composition of all reagents used in R.C.M. work is published in the bulletins (1, 2) devoted to the subject. At the very beginning of the adoption of R.C.M. by Hawaiian plantations it was recommended that all plantations obtain their reagents from a central source to insure uniformity of these products and thus avoid irregularities in quality and condition of reagents. It was pointed out that unless general adherence to this plan was observed it would prove practically impossible to conduct accurate checking determinations at the Experiment Station of duplicate soil or plant specimens which various plantation analysts had previously analyzed and which had been forwarded to Honolulu (as is the present rule at periodic intervals) in order to check the reliability of plantation analyses from time to time.

While it is true that the exact chemical composition of all reagents is recorded in the bulletins, it is also true that their preparation involves experience, the purchase of large quantities of chemicals which have to be reanalyzed before use and a knowledge of chemistry. Some reagents are prepared in large volume and stored for 6 months or longer for secondary reactions to subside before they can be

properly standardized and checked preparatory to packaging for Experiment Station or plantation use. Other reagents deteriorate upon standing and must be prepared in small lots and at frequent intervals. Still others are affected by alkali in glass containers and must be packaged in bottles which have been coated on the inner surfaces with a thin but substantial lining of flexible and inert wax. These and other considerations make it imperative that responsibility for the manufacture and distribution of all reagents used by all groups of R.C.M. workers in a given confine be centralized in one laboratory.

Deviation from this practice has invariably led to disaster in the few cases which have occurred in Hawaii. Two of these will be cited briefly because of the far-reaching effects which were produced in temporary but serious disruptions of the personnel and organization of two large plantations.

A plantation manager wrote to the Experiment Station stating that although he had established an R.C.M. laboratory and staff of analysts he had found that the system could not be used with the soils of his locality. To support his claim he described a test of the system which had been made that day in which a certain field soil failed to show even a trace of phosphate by R.C.M. and yet field experiment and Mitscherlich studies had indicated that the phosphate reserves in this soil were so high that additional phosphate nutrient was not required. To clinch his case he described another test in which a soluble phosphate fertilizer was added to the soil in question immediately before analysis by R.C.M. The analysis revealed even in this instance no trace of phosphate. He requested authorization to return all equipment and reagents to the Experiment Station and stated that the laboratory would have to be discontinued.

A visit was made by one of us to this plantation by overnight steamer. The investigation which followed disclosed that a laboratory analyst—from the best of motives—offered to purchase the necessary chemicals from a local drug store and prepare the reagents as they were needed, using the R.C.M. bulletins and notes he had compiled during his period of training at the Experiment Station. His offer was accepted by the agriculturist. As may be expected, this man ran afoul of the complications involved in processing ammonium molybdate for Reagent No. 4. Also, his stannous chloride solution had completely oxidized, was not stored over metallic tin and had the appearance of skim milk in his service dropping bottle. The chemicals he purchased were also at fault in that they were not of reagent quality. Hence, due to the combined effects of the circumstances cited, R.C.M. analyses broke down completely in this laboratory. The manager did not appear to know that one of his analysts was preparing reagents.

In anticipation of the likely trouble, small quantities of the two properly prepared reagents mentioned above were taken to the plantation at the time of the visit. A demonstration by the visiting chemist to the manager, agriculturist and laboratory staff—using the properly prepared reagents—soon clarified the situation. Immediately thereafter the homemade reagents were thrown away, new supplies were ordered from the Experiment Station and in a few days the laboratory was reestablished. It is functioning today (6 years later) without apparent difficulties.

The other case involved Experiment Station reagents as used in the soil potash determination. Another plantation manager wrote to the Experiment Station and took us to task for supplying reagents which he and his staff had been convinced

were worthless. He stated that he could not afford to abandon his R.C.M. soil survey and since we apparently were not preparing high-grade reagents he was about to arrange with a mainland manufacturer to supply first-class materials. Proof of his claim was submitted in comparison test data in which Experiment Station reagents were used separately as compared with similar reagents obtained at appreciable expense and trouble by fast express from a laboratory in the middle west. The data clearly showed our reagents to be absolutely useless. They were. There was no doubt of it. An immediate investigation by one of us brought out the fact that as a prank a plantation worker in the mill laboratory removed about 75 per cent of Reagent No. 3 from the stock container in the R.C.M. laboratory and substituted water in its place. This reagent is used to precipitate potash for a turbidity reading after agitation on the rotator. It must contain at least 80 per cent of absolute alcohol to accomplish the desired purpose. In addition to this difficulty, Reagent No. 2, a cobaltous and very unstable compound, had been purchased from the Experiment Station in an entirely too large amount a year or more previously and through exposure to sunlight and by returning daily unused portions of the reagent to the stock container each evening the entire lot had thoroughly decomposed. Adjustments were made to the satisfaction of the management and staff and this laboratory is successfully operating today using, exclusively, Experiment Station service facilities and reagents.

These and a few similar experiences have made it possible to compensate for difficulties of this character and to establish a system of reagent and equipment control which is quite effective in its reliability and uniformity. However, emphasis is still stressed on the obviously essential "unit source of supply." The cost of reagents to plantation and other users is based upon the cost of chemicals plus the expenses incurred in preparing, bottling, packing and shipping them. All other services on R.C.M. matters tendered by the Experiment Station to plantations and associate users are not subject to a direct charge.

The Plantation-Experiment Station Checking System

This system was described fully in Bulletin 50. Briefly stated, it operates as follows: The plantation agriculturist (not the analyst) will place aside about a 1-pound representative portion of, say, every fiftieth soil specimen which has previously been collected and prepared for analysis, and a sufficient quantity of occasional plant material from every series of samples which are undergoing analysis in the plantation laboratory. At from a 2-week to 1-month interval these reserved samples are sent by parcel post to the Experiment Station with a copy of the corresponding analytical data reported by the R.C.M. analysts on these analyzed materials. The plantation R.C.M. staff is acquainted with the fact that a certain number of their analyses are to be repeated by the Experiment Station on the residues of specimens which they have previously worked. They do *not* know how many or which samples are to be checked.

Upon arrival at the Experiment Station the samples are assigned to any one of several Experiment Station analysts for repeat determinations. When the analyses are completed the results are compared with the plantation figures and, if necessary, assigned to a second or even a third Experiment Station analyst for recheck or verification. A report is then rendered the plantation manager, show-

ing comparison data (his and ours). Comments and suggestions are made on the comparison figures and recommendations are included, when appropriate, which are designed to assist the plantation analyst in correcting his technic, testing his reagents or in making a more exacting repeat analysis for his own satisfaction.

A typical example is given below of original data and Experiment Station comparison figures as determined soon after it was learned that a plantation R.C.M. staff had been finding it increasingly difficult to obtain concurring results in their soil potash work.

An Experiment Station analyst was assigned to cooperate with the plantation men in locating and correcting the difficulty. A set of comparison figures follows

"X" AGRICULTURAL COMPANY, LIMITED

Soil Analyses

	Phosphate, P_2O_5						Potash, K_2O					
	%		Lbs./a-ft.		Group		%		Lbs./a-ft.		Group	
Soil No.	HSPA	Pltn.	HSPA	Pltn.	HSPA	Pltn.	HSPA	Pltn.	HSPA	Pltn.	HSPA	Pltn.
14388, 2A1	+.032	+.032	+800	+800	High	High	.018	.010	450	250	High	Med.
14389, 4	+.032	+.032	+800	+800	High	High	.004	.003	100	75	Low	Low
14390, 1B	+.032	.010	+800	250	High	Dbt.	.014	.006	350	150	High	Dbt.
14391, 2	+.032	+.032	+800	+800	High	High	.010	.009	250	225	Med.	Med.
14392, 3	.0034	.0015	85	38	Med.	Med.	.012	.012	300	300	Med.	Med.
14393, 4	.010	.0015	250	38	High	Med.	.009	.010	225	250	Med.	Med.
14394, 14A	.006	.005	150	125	High	High	.011	.014	275	350	Med.	High
14395, 3	.004	.0028	100	70	High	Med.	.005	.007	125	175	Dbt.	Dbt.
14396, 9	.007	.007	175	175	High	High	.012	.009	300	225	Med.	Med.
14397, 4	.0006	.0002	15	5	Low	Low	.011	.009	275	225	Med.	Med.

Note: Plus sign denotes quantity greater than that indicated.

disclosing the potash irregularity. The entire comparison data of P_2O_5 and K_2O are included. Note the time interval, please, for reference to a succeeding and similar check.

In due course the difficulty was located at the plantation, explained fully to the staff and the work was reorganized without incurring ill feeling of any kind. Several weeks went by before another Station check was made. In the meantime the plantation staff reported that their former soil potash difficulties had ceased. Later, an extensive checking comparison was again made. The data follow:

"X" AGRICULTURAL COMPANY, LIMITED

Soil Analyses

	Phosphate, P_2O_5						Potash, K_2O					
	%		Lbs./a-ft.		Group		%		Lbs./a-ft.		Group	
Soil No.	HSPA	Pltn.	HSPA	Pltn.	HSPA	Pltn.	HSPA	Pltn.	HSPA	Pltn.	HSPA	Pltn.
202....	.006	.006	150	150	High	High	.003	.003	75	75	Low	Low
204....	.006	.006	150	150	High	High	.005	.004	125	100	Low	Low
205....	.0015	.0010	38	25	Med.	Dbt.	.004	.003	100	75	Low	Low
207....	.0028	.0020	70	53	Med.	Med.	−.003	.003	− 75	75	Low	Low
209....	.004	.004	100	100	High	High	−.003	.003	− 75	75	Low	Low
210....	.0028	.0028	70	70	Med.	Med.	−.003	.003	− 75	75	Low	Low
212....	.015	.015	375	375	High	High	.014	.014	350	350	High	High
229....	+.032	.032	+800	800	High	High	.025	.025	625	625	High	High
231....	.004	.004	100	100	High	High	.004	.003	100	75	Low	Low
233....	.0021	.0028	53	70	Med.	Med.	−.003	.003	− 75	75	Low	Low
234....	.0012	.0011	30	27	Dbt.	Dbt.	.004	.003	100	75	Low	Low
235....	.0012	.0012	30	30	Dbt.	Dbt.	.004	.003	100	75	Low	Low
237....	.0015	.0012	38	30	Med.	Dbt.	.005	.003	125	75	Dbt.	Low
238....	.0028	.0021	70	53	Med.	Med.	.006	.005	150	125	Dbt.	Dbt.
241....	.004	.0034	100	85	High	Med.	.004	.004	100	100	Low	Low
242....	.0028	.0021	70	53	Med.	Med.	−.003	.003	− 75	75	Low	Low
245....	.0028	.0028	70	70	Med.	Med.	.004	.004	100	100	Low	Low
246....	.0012	.0012	30	30	Dbt.	Dbt.	.0055	.005	138	125	Dbt.	Dbt.
248....	.0012	.0012	30	30	Dbt.	Dbt.	.004	.003	100	75	Low	Low
250....	.0034	.0034	85	85	Med.	Med.	.006	.006	150	150	Dbt.	Dbt.

Note: Plus sign denotes quantity greater than that indicated.
Minus sign denotes quantity less than that indicated.

The improvement, it may be observed, is substantial and real. Rigorously pursuing a checking system appears to justify the effort.

Training Experiment Station and Plantation Workers, University Students and Others in R.C.M.

As its designation implies, R.C.M. determinations must be rapidly performed. Of greater import, however, they must be accurate, subject to analytical check and not require elaborate equipment. Simplicity of performance makes them adaptable to use by those previously untrained in chemistry. However, it has been found by our own experiences that a short course of organized instruction in R.C.M. actually fits the student for quite a satisfactory performance in this work, regardless of his previous training. It has also been found that instruction in the general theory of chemical analysis, although not essential, is a decided help in enabling the analyst to grasp the significance of the determination as well as perform the required analytical steps with a greater degree of assurance and understanding. The course of instruction, therefore, embraces a training in performing successive steps in the various analyses and includes an explanation of the chemistry of the analysis and the reasons which govern the progressive movement of the determination to its analytical conclusion.

The time devoted to the course varies between 10 days and 4 weeks, depending entirely on the aptitude of the student and upon the number of determinations required to complete his curriculum.

Instruction is given by department chemists, all graduates, who have contributed to the development of R.C.M. and who are engaged in identical studies in the Experiment Station laboratories.

Those taking the courses are principally plantation young men having high school or more extended education. They are sent to Honolulu at the expense of the plantation, returning for duty after showing proficiency in a standard graded series of performance examinations given the candidate at the conclusion of his course of instruction. Others taking the course include all students-in-training of the Agricultural department, this Experiment Station; a number of students taking work at the University of Hawaii; and occasionally a visiting agricultural scientist from the mainland or from another country.

Modifications of Existing R.C.M. Procedures

Phosphate:

A simple, but greatly improved procedure which should be used in the analysis of soils which are well supplied with phosphate is as follows: In the present procedure the extracted and purified phosphate residue is dissolved in 10 ml. of Reagent 4, P_2O_5. A portion of this solution is added to a phosphate vial (a vial which also should be calibrated to a standard internal diameter), filling the tube to within a quarter inch of the top. Stannous chloride reagent is added to develop the color. However, if the color developed is darker than the deepest hued color standard, then the analyst transfers half of his test solution to a clean, dry vial and adds an equal volume of Reagent 4, P_2O_5. Thereupon the color is brought to full intensity again by adding additional stannous chloride reagent.

Due to the fugitive nature of the developed color reimposed upon a similarly treated test specimen, L. Kawamura and E. Watanabe have found by long experience that a modification of this procedure gives much more reliable and satisfactory results.

The modification consists in separating 10 ml. of the solution of the purified phosphate residue into two vials, the *first* containing about 3½ ml. and the *second* the remainder (approximately 6½ ml.) of the solution. Now, develop the color as usual in the second vial. If the blue color produced is too intense, add 3½ ml. of Reagent 4, P_2O_5 to the reserved 3½ ml. of dissolved phosphate and proceed as usual, using a factor of 2 in recording the result to compensate for the dilution.

The correct dimensions of standard phosphate vials should approximate 12½± mm. outside diameter, 11± mm. inside diameter, by 102 mm. length.

Total Nitrogen:

A suggestion follows regarding the determination of total nitrogen by R.C.M. Near the close of the procedure, when distilling off the ammoniacal fraction from the reaction chamber, standard practice has continued the distillation until the volume of the distillate reached a predetermined level marked by an etched ring on the receiver. Later, when the distillate cools to room temperature and the volume of the distillate, as a consequence, has shrunk below the marked level, distilled water is added to make up the loss in volume.

It has been found in practice that better results may be secured, with fewer manipulations, and that greater assurances may be had that all of the ammonia has been distilled over if the distillation is continued until the level of the distillate reaches a point about one-eighth inch above the mark on the receiver. By following this practice, it will be found that upon cooling, the volume of distillate, as a rule, stands at the prescribed level and, therefore, it will not have to be tampered with prior to concluding the determination.

Available Nitrate Nitrogen:

Difficulties have been encountered in this determination in securing a sufficiently rapid reaction of Reagent 7, N with the residue obtained upon evaporation of the 25-ml. filtrate. It is suggested, therefore, that after the residue from the filtrate has been obtained by evaporation the crust formed be loosened and broken up with a glass rod before the addition of Reagent 7, N. If this simple modification is adopted we believe it will result in a more rapid and a more satisfactory determination.

A Refinement in the R.C.M. Determination of Phosphate in Soil:

This modification in analytical procedure, when substituted for that now in use, does not detract from correlation values already considered or from those to be determined. The refinement is a development resulting from research which has been in progress for some time on all R.C.M. procedures and which will continue in the future. The magnitude of correction in soil phosphate values with most soils, of course, will be found insignificant. In such cases the modification may be disregarded. However, the simplicity of the revised procedure renders the checking of the point a very easy and inexpensive matter. Interference with the estimation of phosphate in soil as occasioned by the presence of calcium, silicates,

nitrates, carbonates, ferrous iron, or traces of selenium, arsenic, titanium, aluminum, or manganese are eliminated in this simple analytical revision.

A number of common or of rarer soil constituents, which may or may not be present in any given soil, react in the phosphate determination in a manner which fictitiously increases the final reading to a variable degree. To insure greater accuracy, it is recommended that the following modification of the R.C.M. determination of phosphate in soil, (a development by T. Nishimura, Assistant Chemist), be used in all laboratories, *provided* the modified procedure shows consistently a *lower,* though but slightly smaller concentration of the nutrient than the result obtained on the same soil with the existing method.

Modified Procedure: Treat the soil by the regular procedure for the rapid estimation of phosphate in soils up to and including the close of operations in Step No. 10. Then:

1. To the concentrated hydrochloric acid-treated residue, add 20 drops of Reagent 11, P_2O_5 from a dropping bottle.
2. Evaporate to dryness as usual on an electric hot plate.
3. Add 20 drops of concentrated hydrochloric acid and evaporate again.
4. Now, add 10 drops of concentrated nitric acid and evaporate to dryness.
5. Add 10 drops of concentrated hydrochloric acid and again evaporate to dryness. Repeat the addition of concentrated hydrochloric acid and evaporate to dryness once more.
6. Proceed with Step No. 11 of the regular procedure as usual and continue with the rapid estimation of phosphate in soil.

Interfering substances are volatilized or rendered impotent by the modified treatment. Reagent 11, P_2O_5 consists of a mixture of hydrobromic and hydrochloric acids. The appearance of a reddish coloration in the residue after the bromine treatment may be expected. It will be dissipated, however, by the subsequent nitric acid digestion.

Note: Reagent 11, P_2O_5 is prepared by mixing 25 ml. of hydrobromic acid (48%, sp.gr. 1.5) and 75 ml. hydrochloric acid (sp.gr. 1.18 - 1.19). Store the solution in an amber-colored, glass-stoppered bottle.

Leaf-Punch Nitrogen:

Procedure:

1. Obtain samples in the field from growing cane.
2. The procedure is based on sampling a definite grouping of leaves of the plant but with random selection of stalks. In general, the object consists in obtaining a representative sample of cane growing in a field. In a stand of cane there may exist different orders of stalks, including tasseled and untasseled canes. Experience thus far has indicated that for consistency of results only the untasseled cane should be sampled. In selecting stalks for sampling, as much of the primary growth is included as may be consistent with the principle of random selection.

To insure reliability of results two composite samples are obtained from each field. Two sampling stations are thus established per field, each station comprising an area of about 25 feet square (25′x25′). Sixty leaf-punch disks constitute a sample. Two disks are taken from each leaf in a region located about halfway along the blade and about one half the distance between the midrib and the outer

edge of the leaf. The two disks may be spaced about an inch apart along the blade. The critical sampling zone comprises that portion of the leaf system represented by the 4th, 5th and 6th leaves, counting from the top of the plant, according to the Clements-Martin system of nomenclature. In this system the spear-like spindle, if definitely visible, is counted as the first leaf, the adjacent leaf enfolding this spindle as the second leaf, and the numbering then proceeds consecutively downward along the stalk. Sometimes this spear-like spindle is not definitely visible, but in its place is found a leaf just beginning to unfurl; this, then is counted as the first leaf. These three designated leaves (4th, 5th and 6th) appear to comprise that portion of the plant which will yield reliable information concerning the "nitrogen index." (The nitrogen content percentage of the specimen has been termed the "nitrogen index" by H. P. Agee.)

Sampling may start with cane about three months of age. For young cane, not yet head high (less than 6 feet from base to top of foliage), only the 4th leaf is punched. As the plant grows, the 5th and 6th leaves are included. The full complement of 4th, 5th and 6th leaves may be sampled usually after the cane has reached or exceeded the above designated height. When the full complement of leaves comprises the material to be sampled, ten stalks are selected for the purpose in each station. For young cane, a sufficient number of stalks are selected to insure a 60-disk sample.

3. Where it is desired to obtain leaf specimens before the plant reaches an age of three months, cane growing not longer than a period of two months may be sampled. In such a case only the third leaf should be punched and this obvious deviation from the regular sampling order should be recorded with the analytical data accruing from the analysis.

4. Transfer disks to a small tin box and cover securely.

5. Remove cover and dry in electric oven at 100° C. for 3 hours, or at 80° C. for 5 hours (or overnight). (Cover and receptacle may be nested.) When dry, remove cans from oven; replace covers. Place cans in a desiccator and cool for 15 minutes, or longer. Obtain dry weight of sample by transferring it to tared scoop and weighing on analytical balance. Record the dry weight.

6. Transfer the disks to a Kjeldahl flask of 300-ml. capacity.

7. Drop 2 glass beads or one porous granule into the flask; add ⅓ of a small horn spoonful of potassium sulfate (K_2SO_4) powder. Introduce 4 ml. of Reagent 15, total N with the special pipette. Let stand for about 5 minutes. (Where an efficient hood to exhaust noxious fumes from the laboratory is not available, fit a Hengar tube into the neck of the flask.)

Place the Kjeldahl flask on the heater to digest; digest for ½ hour. Using the wooden clamp, remove flask to the box and cool to room temperature. Add 100 ml. of Reagent 18, total N from a graduated cylinder, washing down the neck of the Kjeldahl flask. Let stand to cool.

Add 15 ml. of Reagent 16, total N to a 200x29 mm. calibrated test tube. Immerse in cold water in a 500-ml. Erlenmeyer flask. Set flask and tube on iron support shelf and arrange this unit adjacent to heater unit for the distillation.

With the solution in the Kjeldahl flask at room temperature, add 20 ml. of Reagent 17, total N from the special dispensing burette. Turn on heater current.

Immediately attach the connecting bulb assembly, stoppering "trap end" tightly with the flask. The outlet tube is put into the test tube with the tip momentarily withheld above the level of Reagent 16, total N while the mixture in the Kjeldahl flask is stirred thoroughly. After mixing, the tip of the distillation outlet tube is immersed in the 15 ml. of Reagent 16, total N.

Place the Kjeldahl flask on the heater. Distillation is continued until the distillate reaches the level marked on the test tube, when the water flask and tube are immediately removed from the distillation outlet. The heater may then be turned off and the connecting bulb assembly removed. The test tube is removed from the Erlenmeyer flask and placed on the tube rack to cool. Cool distillate to room temperature.

8. Make volume exactly up to the 50-ml. mark with Reagent 18, total N. *(Note:* Distillate may also be collected following the procedure outlined under the modification suggested for "Total Nitrogen.") Stopper test tube with a No. 6 rubber stopper and mix contents thoroughly by inverting several times.

(a) In general, a mixture of 1 ml. of distillate plus 5 ml. of Reagent 18, total N and an 0.50 ml. of distillate plus 5 ml. of Reagent 18, total N will cover the range of nitrogen found in the sample. However, the table of readings to follow will cover any extremes, provided approximately 60-disk samples are taken.

9. (a) Using a special 1-ml. (calibrated to 0.1 ml.) Mohr pipette, transfer 1-ml. aliquots of the distillate to each of two comparison vials. Add 5 ml. of Reagent 18, total N with a special 5-ml. Mohr pipette. Add 1 ml. of Reagent 6, N to each tube. Stopper and let stand 1 minute; mix if necessary. Then compare with color standards on the illuminator.

(b) Repeat procedure with another set of two vials, but use an 0.50-ml. aliquot of the distillate plus 5 ml. of Reagent 18, total N.

(c) When proficiency in reading and matching color standards has been attained, the two different proportional mixtures may be made up at one time, developed, allowed to stand the 1-minute interval and then read.

(d) The other dilutions listed in the table of readings (0.25 ml. of distillate plus 5 ml. of Reagent 18, total N and 1.5 ml. of distillate plus 4.5 ml. of Reagent 18, total N) are only to be used when the 1-ml. and 0.5-ml. aliquots are unsatisfactory because of a too light or too dark color development. Standard tubes which give most satisfactory results are those between 3 and 6, inclusive.

10. Refer to the table of readings for data on the percentage of nitrogen in cane leaves. (The fractions between standard numbers of the table refer to the position of the unknown to its approximate matching between two adjacent standards.)

11. Refer to the table of factors for dry weight.

12. Factor *times* Reading = per cent total N (dry basis). The average of the two percentages will give the result for the analysis of the sample.

Field ______ Variety ______ Fert. N ______

Acres ______ Crop ______ P_2O_5 ______

Sta. No. ______ K_2O ______

Date Spld.	Age Spld.	Growth Measurements						N - Index			
										Average	

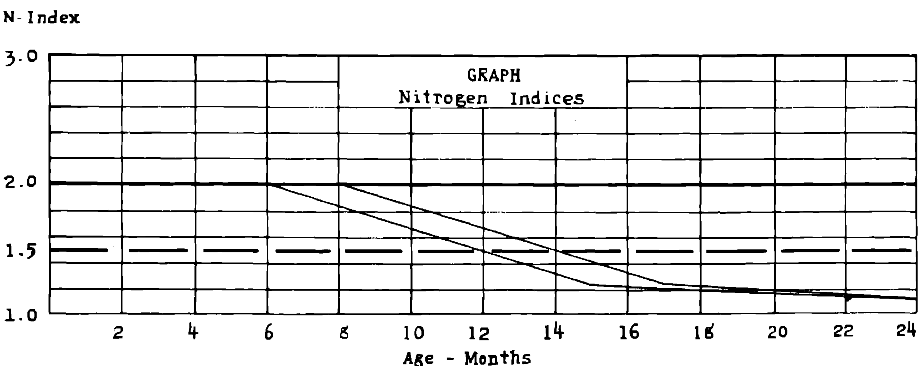

Fig. 1

Example:

(*a*) Dry weight of sample=0.0812 gram

(*b*) Distillate analysis, Reading:

Dilution 1 and 5=0.180 Reading

Dilution ½ and 5=0.176 Reading

(*c*) Referring to table of factors for dry weight, 0.081 gram, Factor=12.3

(*d*) Per cent total N=Factor *times* Reading

$$\left.\begin{array}{l}\text{1 ml.+5 ml. dilution—}12.3\times0.180=2.21\%\text{ total N}\\ \text{0.5 ml.+5 ml. dilution—}12.3\times0.176=2.16\%\text{ total N}\end{array}\right\}2.19\%$$

(*e*) or averaging the two Readings:

$$\left.\begin{array}{l}0.180\\0.176\end{array}\right\}0.178\text{ (average reading)}$$

and multiplying by Factor:

$0.178\times12.3=2.19\%$ (result for the sample).

A form has been developed for recording the leaf-punch nitrogen data obtained in this type of study. It is illustrated in Fig. 1. Spaces are provided for data pertinent to field, crop and fertilization. Tabular columns are included for recording date of sampling, age of cane at sampling, growth measurement data if taken, the nitrogen index values and remarks. At the bottom of the page a form is appended for plotting a graphical presentation of the nitrogen data. The nitrogen percentages are placed on the ordinate and the age in months on the abscissa.

TABLE OF READINGS FOR N DETERMINATION IN LEAF-PUNCH SAMPLES WHERE ENTIRE SAMPLE IS DISTILLED

(Dilutions below, refer to treatment of distillate)

		Dilution		
Standard No.	1 ml.+5	0.50 ml.+5	0.25 ml.+5	1.5 ml.+4.5
1	.012	.022	.042	.008
.25	.018	.033	.063	.012
.50	.024	.044	.084	.016
.75	.030	.055	.105	.020
2	.036	.066	.126	.024
.25	.042	.077	.147	.028
.50	.048	.088	.168	.032
.75	.054	.099	.189	.036
3	.060	.110	.210	.040
.25	.066	.121	.231	.044
.50	.072	.132	.252	.048
.75	.078	.143	.273	.052
4	.084	.154	.294	.056
.25	.090	.165	.315	.060
.50	.096	.176	.336	.064
.75	.102	.187	.357	.068
5	.108	.198	.378	.072
.25	.117	.215	.410	.078
.50	.126	.231	.442	.084
.75	.135	.248	.473	.090
6	.144	.264	.504	.096
.25	.153	.281	.536	.102
.50	.162	.297	.567	.108
.75	.171	.314	.598	.114
7	.180	.330	.630	.120
.25	.195	.358	.682	.130
.50	.210	.385	.735	.140
.75	.225	.413	.788	.150
8	.240	.440	.840	.160

The above data are merely readings. To obtain per cent total nitrogen (dry basis) in the sample, multiply Reading by Factor for dry weight.

Reading *times* Factor=% total N (dry basis).

TABLE OF FACTORS FOR DRY WEIGHT

The following factors are obtained by the formula:

$$\text{Factor (F)} = \frac{1}{\text{Dry weight of sample}}$$

Dry weight	Factor	Dry weight	Factor	Dry weight	Factor
.040	25.0	.060	16.7	.080	12.5
.041	24.4	.061	16.4	.081	12.3
.042	23.8	.062	16.1	.082	12.2
.043	23.2	.063	15.9	.083	12.0
.044	22.7	.064	15.6	.084	11.9
.045	22.2	.065	15.4	.085	11.8
.046	21.7	.066	15.1	.086	11.6
.047	21.2	.067	14.9	.087	11.5
.048	20.8	.068	14.7	.088	11.4
.049	20.4	.069	14.5	.089	11.2
.050	20.0	.070	14.3	.090	11.1
.051	19.6	.071	14.1	.091	11.0
.052	19.2	.072	13.9	.092	10.9
.053	18.9	.073	13.7	.093	10.8
.054	18.5	.074	13.5	.094	10.6
.055	18.2	.075	13.3	.095	10.5
.056	17.8	.076	13.2	.096	10.4
.057	17.5	.077	13.0	.097	10.3
.058	17.2	.078	12.8	.098	10.2
.059	16.9	.079	12.6	.099	10.1
.060	16.7	.080	12.5	.100	10.0

New R.C.M. Procedures

Rapid Estimation of Total Phosphate in Soils:

Weigh 0.25 gram of 100-mesh soil into a 60-ml. glazed porcelain dish. Add 2 to 2.5 grams of flux ($2Na_2CO_3 + 1Li_2CO_3$) in about 3 portions, intimately mixing each addition with a glass rod.

To a 40-ml. nickel crucible, add a thin layer of the flux and press down lightly. Transfer the prepared mixture from the dish with a spatula and cover it with an additional thin layer of flux.

Cover the crucible and fuse on the Type "H" electric hot plate at full heat. Continue heating until all bubbling ceases (½ hour). Remove the crucible from heater, using tongs, and give a rotary motion to the fused mass so that most of it will solidify on the sides of the crucible. (This procedure will facilitate the solution of the solid mass which, after cooling, is placed in a 250-ml. beaker.)

Place the crucible with its contents and cover in a 350-ml. beaker containing 75 ml. of H_2O and approximately 1 gram of ammonium carbonate. After boiling gently for about 5 minutes, remove and hold the crucible and lid separately over the beaker and wash each carefully with distilled water, making sure that all the washings are collected in the beaker. Break up with the glass rod any insoluble residue adhering to the crucible or cover.

Filter the solution in the beaker through a Munktell No. 0, 11-cm. filter paper and wash the filter and residue thoroughly with hot water, reserving all filtrate and washings in the receiving beaker.

Evaporate filtrate almost to dryness (avoid spattering) with 2 ml. of con-

centrated HCl. (Acid to methyl red or methyl orange indicator.) Add 20 drops of Reagent 11, P_2O_5 and evaporate again. Repeat evaporation with 2 ml. of concentrated HCl.

Eliminate excess bromine with a few drops of HNO_3 and evaporate to dryness. Repeat evaporation with 2 ml. of concentrated HCl. Evaporate to dryness twice more with 1 ml. of concentrated HCl.

Take up the evaporated residue in the beaker with exactly 50 ml. of Reagent 4, P_2O_5. Insure complete solution of residue by stirring with a glass rod. If insoluble substance (SiO_2) persists, filter through a wad of clean, dry cotton. This clear filtrate is now ready for P_2O_5 determination by the regular R.C.M. for phosphate.

Pipette with a 5- or 10-ml. Mohr pipette a suitable aliquot, ranging from 1 to 8 ml., into a phosphate comparison tube. (Make up the aliquots to a total volume of 8 ml. with Reagent 4, P_2O_5 on all comparisons.) Mix the contents of the tube thoroughly.

Add one drop of stannous chloride solution to the tube, mix again and immediately compare with the phosphate color standards for cane juice, using the phosphate illuminator. Note result. Continue with the addition of stannous chloride solution, drop by drop, until a maximum blue color is developed. After the addition of each drop of stannous chloride solution, cover the open end of the vial with finger, rock back and forth, and immediately compare with the standards.

Record the result obtained by the maximum blue color as per cent P_2O_5 by referring to the table for total phosphate in soils. Employ the technic of selecting aliquots for comparison as indicated in the example given below. If possible, select aliquots which will develop a color intensity comparable to standard tubes Nos. 4 to 8, inclusive.

Example: If a 5-ml. aliquot approximately matches Tube No. 4, giving 0.32 per cent, check the result by selecting aliquots from the table which gives percentages in the vicinity of 0.32 per cent, such as:

ml. aliquot	%	Std. tube No.
5.00	0.32	4
5.25	0.31	4+
5.50	0.29	4+
5.75	0.33	5—
6.00	0.32	5
6.25	0.31	5+
6.50	0.30	5+
6.50	0.34	6—
6.75	0.33	6—
7.00	0.32	6
7.25	0.31	6+
7.50	0.30	6+
7.75	0.33	7—

Rapid Determination of Phosphate (P_2O_5) in Cane Root Material:

Preparation of Sample: Obtain fresh root material and wash off any adhering soil particles or foreign matter. Dry in an electric drying oven at about 100° C.

RAPID ESTIMATION OF TOTAL PHOSPHATE IN SOILS

0.25-gram soil fusion extract made up to 50 ml.—Figures in % phosphate, P_2O_5

Std. No.	ml. aliquots 1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75
1......	0.64	0.512	0.427	0.366	0.32	0.284	0.256	0.233	0.213	0.197	0.183	0.171	0.160	0.151	0.142	0.135
2......	0.96	0.768	0.640	0.549	0.48	0.427	0.384	0.349	0.320	0.295	0.274	0.256	0.24	0.226	0.213	0.202
3......	1.28	1.204	0.853	0.731	0.64	0.569	0.512	0.465	0.427	0.394	0.366	0.341	0.32	0.301	0.284	0.269
4......	1.60	1.280	1.067	0.914	0.80	0.711	0.640	0.582	0.533	0.492	0.457	0.427	0.40	0.376	0.356	0.337
5......	1.92	1.536	1.280	1.097	0.96	0.853	0.768	0.698	0.640	0.591	0.549	0.512	0.48	0.452	0.427	0.404
6......	2.24	1.792	1.493	1.280	1.12	0.996	0.896	0.815	0.747	0.689	0.640	0.597	0.56	0.527	0.498	0.472
7......	2.56	2.048	1.707	1.463	1.28	1.138	1.024	0.931	0.853	0.788	0.731	0.683	0.64	0.602	0.569	0.539
8......	2.88	2.304	1.920	1.646	1.44	1.280	1.152	1.047	0.960	0.886	0.823	0.768	0.72	0.678	0.640	0.606

Std. No.	ml. aliquots 5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00
1......	0.128	0.122	0.116	0.111	0.107	0.102	0.098	0.095	0.091	0.088	0.085	0.083	0.080
2......	0.192	0.183	0.175	0.167	0.160	0.154	0.148	0.142	0.137	0.132	0.128	0.124	0.12
3......	0.256	0.244	0.233	0.223	0.213	0.205	0.197	0.190	0.183	0.177	0.171	0.165	0.16
4......	0.320	0.305	0.291	0.278	0.267	0.256	0.246	0.237	0.229	0.221	0.213	0.206	0.20
5......	0.384	0.366	0.349	0.334	0.320	0.307	0.295	0.284	0.274	0.265	0.256	0.248	0.24
6......	0.448	0.427	0.407	0.390	0.373	0.358	0.345	0.332	0.320	0.309	0.299	0.289	0.28
7......	0.512	0.488	0.465	0.445	0.427	0.410	0.394	0.379	0.366	0.353	0.341	0.330	0.32
8......	0.576	0.549	0.524	0.501	0.480	0.461	0.443	0.427	0.411	0.397	0.384	0.372	0.36

Note: Use comparison tubes of uniform volume in all determinations.

for 3 hours. Grind the dried roots in order to obtain a uniform representative sample for analysis.

Procedure: Weigh out 0.36 gram of the ground root material into a 50-ml. beaker.

Add 1 ml. of Reagent 12, P_2O_5* and insure a good mixture by stirring with a short glass rod. Make a special effort to have the greater portion of the sample at the bottom of the beaker since it will have a tendency to adhere to the sides of the beaker.

Now add 5 drops of concentrated HNO_3 from a dropping bottle, covering as much area as possible. Place the beaker on an open Type "H" electric hot plate (directly upon the coils) and ignite for 5 minutes or until white or gray-colored ash appears.

Remove and cool, then add a few drops (about 10 drops) of concentrated HNO_3 and mix in such a way that the non-ashed root material (usually dark colored) will be at the bottom of the beaker.

Place on an electric hot plate and evaporate to dryness. Then ignite again on the open Type "H" electric heater for 5 minutes. Ash should be nearly white or gray in color.

Cool the ashed material and add 5 drops each of concentrated HNO_3 and HCl. Evaporate to dryness on an electric hot plate. If residue is brown or dark colored, repeat the hydrochloric and nitric acid treatments.

When a yellow-colored or clear residue is obtained, add 5 drops of concentrated HCl and evaporate to dryness. Dissolve the residue in 20 ml. of N/2 hydrochloric acid solution and filter through Munktell No. 3, 7-cm. filter paper.

Pipette 15 ml. of the filtrate into a 100-ml. beaker and evaporate to dryness. Add 15 ml. of Reagent 4, P_2O_5 to the cooled residue and stir thoroughly.

Using a 5-ml. Mohr pipette, transfer 5 ml. of the solution into a phosphate vial and make up to 8 ml. with Reagent 4, P_2O_5. (For all subsequent aliquots taken for comparison, bring the volume up to 8 ml. with Reagent 4, P_2O_5.)

Develop blue color with an appropriate amount of stannous chloride solution and compare with the phosphate color standards for cane juice. (Use the regular R.C.M. technic for color development.) When the developed color does not match any standard tube, make an estimation of the percentage of P_2O_5 and verify the result by selecting aliquots from the table which will exactly match with a standard tube, preferably between standard tubes Nos. 3 to 6, inclusive.

Example:

5-ml. aliquot plus 3 ml. of Reagent 4, P_2O_5 matches color about ½ way between standard tubes Nos. 4 and 5.

Referring to the table and interpolating,

Tube No. 4—0.089 per cent
Tube No. 5—0.107 per cent

The percentage ½ way between them is 0.098 per cent.

Again referring to the table, 4.5-ml. aliquot with Tube No. 4 gives 0.099 per cent.

For confirmatory test, take a 4.5-ml. aliquot from the test solution, add 3.5 ml. of Reagent 4, P_2O_5 and make comparison. If the interpolation is correct, the color developed should match Tube No. 4.

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* This reagent is prepared by dissolving 100 grams C.P. magnesium nitrate, $Mg(NO_3)_2 \cdot 6H_2O$, in 100 ml. of distilled water.

Should the developed color be more intense than tube No. 8 (greater than 0.16 per cent), dilute the remaining test solution by adding to it an equal volume of Reagent 4, P_2O_5, i.e., if 10 ml. of solution remains, add 10 ml. of Reagent 4, P_2O_5. Stir solution thoroughly.

Proceed with the color development of the 1 + 1 diluted solution. Multiply the result by 2 for percentages on the diluted solution.

PERCENTAGE OF P_2O_5 IN ROOT MATERIAL
(On moisture-free basis)

Aliquots	Standard Tube Nos.							
ml.	1	2	3	4	5	6	7	8
5.00..........	.035	.053	.071	.089	.107	.124	.142	.160
4.75..........	.037	.056	.075	.094	.112	.131	.150	.168
4.50..........	.039	.059	.079	.099	.118	.138	.158	.178
4.25..........	.042	.063	.084	.105	.125	.146	.167	.188
4.00..........	.044	.067	.089	.111	.133	.156	.178	.200
3.75..........	.047	.071	.095	.118	.142	.166	.190	.213
3.50..........	.051	.076	.102	.127	.152	.178	.203	.229
3.25..........	.055	.082	.109	.137	.164	.191	.219	.246
3.00..........	.059	.089	.119	.148	.178	.207	.237	.267

(To obtain results on a 1 + 1 diluted solution, multiply percentages given in the above table by 2.)

Colorimetric Method for the Determination of Sulfate in Cane Juice:

The colorimetric method described utilizes the color formed by sodium rhodizonate and the excess barium chloride which is used to precipitate the sulfate in the sample.

In brief, the method follows: 0.50 ml. of 0.01 N barium chloride solution is added to a measured portion of the juice sample which is placed in a tall vial (phosphate type). The contents of the vial are shaken for ten seconds, allowed to stand one-half minute, made up to 7.0 ml. with distilled water and thoroughly mixed. Three fourths of a ml. of a freshly prepared 0.1 per cent aqueous solution of sodium rhodizonate is added and the contents again mixed to develop the color. The sodium rhodizonate forms a red solution with the excess barium. If there is no excess barium chloride, the solution is yellow.

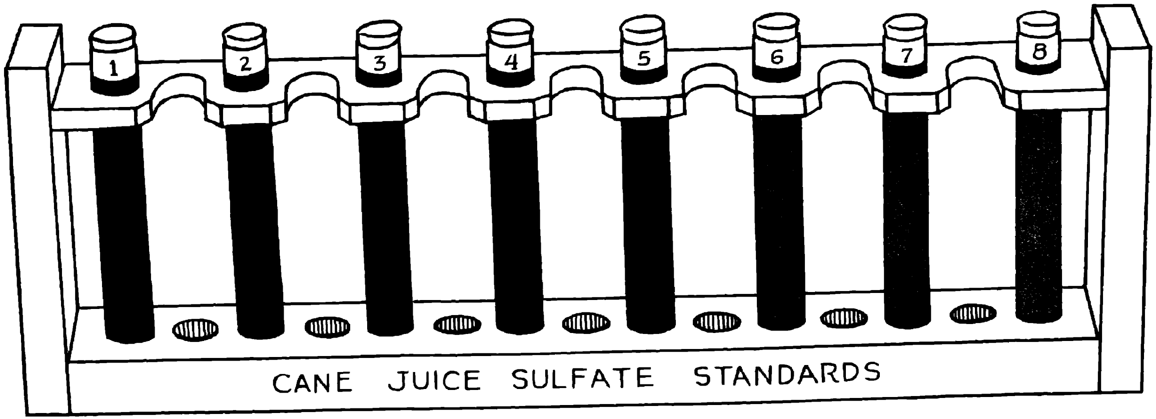
A set of eight permanent inorganic standards, Plate I, has been prepared to cover the range of colors developed. The test solution is compared with the sulfate standards in front of a phosphate illuminator. A table gives the sulfate content in terms of parts per million sulfate for various aliquots of the sample which match each of the standard tubes.

It is necessary to follow precisely the proportions given in the method when using the standards described below. After exhaustive study, the concentrations and proportions of reacting substances given in the following detailed procedure were found to be most satisfactory.

COLORIMETRIC METHOD FOR THE DETERMINATION OF SULFATE IN CANE JUICE

The sealed tubes of color standards are arranged in the order of increasing sulfate content, the lowest being at the extreme left. They are placed in a wooden rack and are numbered progressively from one to eight, the lower figure denoting lower sulfate content.

Unknown solutions in open vials are placed in the intervening spaces and the whole assembly is placed in front of a standard source of illumination for comparison. Reference is made to a suitably prepared table for analytical values. The standards are made from an inorganic salt and are permanent. Full details of preparation, standardization and evaluation appear in the text.


1
2
3
4
5
6
7
8
CANE JUICE SULFATE STANDARDS

Permanent Inorganic Color Standards: In the search for permanent soluble inorganic salts, or combinations of these, to match the colors developed in the test vials in the determination of sulfate we encountered unusual difficulties because the red-colored barium rhodizonate was mixed with small crystals of white barium sulfate. This mixture produced a tinted turbidity instead of clear-colored solutions.

The nearest approximations to the regularly developed test solutions were obtained by etching the outer surfaces of the vials in which the inorganic solutions were sealed. The etching was effected by dipping the stoppered vial, previously treated with cleaning solution, for five minutes in a proprietary etching compound (Jack Frost).

Preparation of Standards: A concentrated aqueous solution of sodium dichromate is used as the base for the standards. Dissolve 250 grams of C.P. sodium dichromate ($Na_2Cr_2O_7.2H_2O$) in distilled water and make up to a total volume of 250 ml. This is Solution *A*. Filter.

Column 2 of Table I shows the quantity of this concentrate to use in making 100 ml. of each standard solution. Column 3 indicates the treatment given the vials in which the inorganic solutions are sealed. The sealing is effected by pouring molten paraffin into the vial filled within 20 mm. of the top with standard solution. A rubber stopper may be pushed into the opening, in which case a little air space is left between the stopper and the paraffin.

TABLE I

Sulfate standard No.	ml. Solution A per 100 ml. of standard	Vial treatment	SO_4 equiv. of standard, in milligrams
1	100	Outer surface etched five minutes by "Jack Frost"	0.048
2	85		0.072
3	63		0.096
4	45		0.120
5	28		0.144
6	12		0.168
7	5		0.192
8	1.5	Unetched tube	0.216

Column 4 gives the sulfate equivalent in milligrams SO_4 of each standard. In Fig. 2, the sulfate content is plotted against the concentration of sodium dichromate in the standards. The smooth curve shows the regularity of the change of color to sulfate content and also serves as a confirmation of the figures experimentally obtained.

Equipment Required:

1 set sulfate color standards in box
6 beakers, Pyrex glass, 100-ml. capacity
6 funnels, glass, 90-mm. diameter
1 volumetric flask, Exax, 10-ml. capacity
1 volumetric flask, Exax, 25-ml. capacity
1 vial block

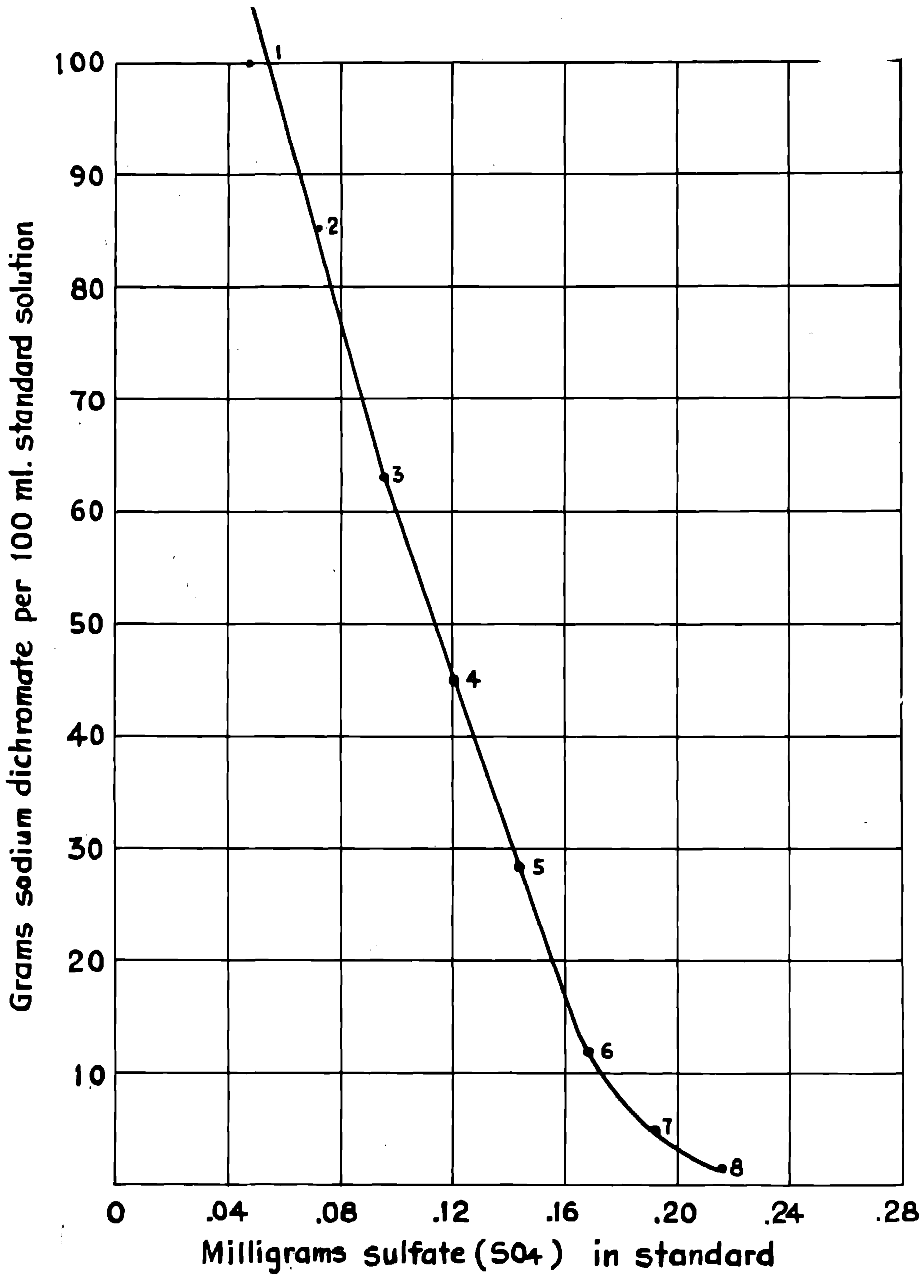


Fig. 2. Graph showing grams of sodium dichromate required to make 100 ml. of each sulfate standard and its sulfate equivalent in mg of SO_4.

1 burette, Exax, 50-ml. capacity, for distilled water
1 box Whatman No. 12, 15-cm. folded filter paper
1 funnel rack, 10-hole
1 phosphate illuminator
2 pipettes, Mohr, 1-ml. capacity, graduated to 0.01 ml.
12 vials, shell, tall-form, calibrated to 7.0 ml.
1 special pipette, 0.75-ml. capacity, with rubber bulb.

Preparation of Special Equipment Required: The tall-form shell vials are calibrated by filling from a 25-ml. burette to 7.0 ml. To prepare the special pipette, draw glass tubing of 7 mm. external diameter to a tip. It is calibrated by counting the number of drops equivalent to 1 ml., then drawing up 1 ml. from a 10-ml. calibrated graduate and letting out one-fourth of the number of drops determined. Scratch a mark at the 0.75-ml. point. Enlarge the upper end to accommodate a small rubber bulb.

Reagents: Sulfate Reagent No. 28, 0.01 N Barium Chloride: Weigh out 1.2216 grams barium chloride ($BaCl_2.2H_2O$), wash into a liter volumetric flask and make up to the mark with distilled water. Preferably, make up a liter of tenth normal barium chloride solution and dilute 100 ml. to 1 liter.

Sulfate Reagent No. 29, 0.1 Per Cent Aqueous Solution of Sodium Rhodizonate: This reagent must be freshly prepared. It loses strength gradually and can be used for only a few hours. Portions of the salt are weighed out into small glass tubes. Take the amount needed and wash completely with distilled water into the size volumetric flask indicated. Make up to volume, stopper and shake until dissolved. Three-fourths ml. of the reagent added to 7.0 ml. of distilled water in the tall vial used for developing the color matches standard No. 8. If the preceding test shows a difference in the shade, the reagent must be discarded.

Procedure: The volume of the samples tested and also of the various reagents used must be measured accurately. Since the volumes employed are exceedingly small, it is necessary to remove any liquid clinging to the outer surface of the pipettes before inserting the latter into the vials. A clean piece of filter paper is suggested for this purpose. Likewise, before the transfer, the tip of the pipette should be touched to the outer surface of the vial and, after the transfer, to the inner surface. This insures more accurate results.

Use fresh, untreated juice or juice to which has been added the preservative employed in rapid chemical methods. Mix the juice thoroughly and filter through Whatman No. 12, 15-cm. folded filter paper. Transfer 0.20 ml. of the juice by means of a 1-ml. Mohr pipette, graduated to 0.01 ml., *to the bottom* of a tall vial (phosphate type).

Add 0.50 ml. of sulfate Reagent No. 28 by means of a pipette, similar to the one used above, to the bottom of the vial containing the juice—shake the contents for ten seconds. Allow the vial to stand ½ minute and dilute with distilled water to the 7.0-ml. mark. Stopper with finger and mix by inverting three times.

Add 0.75 ml. of sulfate Reagent No. 29, using a specially calibrated pipette for the purpose. Mix by inverting the vial three times. Let stand for 10 seconds, then compare with the aid of the phosphate illuminator against the sulfate standards.

If the developed solution is too red, use more juice and repeat the procedure; if the solution is too yellow, use less juice and repeat the procedure.

Use as many aliquots as possible, the colors of which fall within the range of the sulfate standards. Record all the readings. Refer to Table II which gives the sulfate concentration in terms of parts per million for various aliquots used. For the final result, take the average of the figures for the aliquots matching standard No. 3 to standard No. 8, inclusive.

TABLE II

COLORIMETRIC DETERMINATION OF SULFATE IN CANE JUICE

Sulfates (SO_4=) in parts per million

Standard	ml. sample used														
No.	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.60	.70	.80	.90	1.00
1	960	480	320	240	192	160	137	120	107	96	80	69	60	53	48
2	1440	720	480	360	288	240	206	180	160	144	120	103	90	80	72
3	1920	960	640	480	384	320	274	240	213	192	160	137	120	107	96
4	2400	1200	800	600	480	400	343	300	266	240	200	171	150	133	120
5	2880	1440	960	720	576	480	411	360	320	288	240	206	180	160	144
6	3360	1680	1120	840	672	560	480	420	374	336	280	240	210	187	168
7	3840	1920	1280	960	768	640	548	480	426	384	320	274	240	213	192
8	4320	2160	1440	1080	864	720	617	540	480	432	360	309	270	240	216

Comparison of Results: The method has been applied to a number of representative cane juices secured in visits made to all of the plantations on Oahu. Both fresh and preserved juices were analyzed by the colorimetric method described and also by the regular gravimetric method. The results are shown in Table III. It will be noted that although the colorimetric results vary somewhat from the gravimetric figures, the variation is within the limits of the change from one standard to the next.

TABLE III

Juice No.	Plantation	Variety	Treatment of sample	p.p.m. sulfate (SO_4=) Gravimetric	Colorimetric
1	Honolulu	31–2538	Fresh	1370	1450
2	Honolulu	31–2538	R.C.M. preservative	1350	1410
3	Oahu	H 109*	Fresh	868	886
4	Oahu	H 109*	Fresh	1026	1000
5	Oahu	28–3540	Preserved	576	592
6	Ewa	H 109	Fresh	1112	1320
7	Ewa	H 109	Preserved	1142	1200
8	Kahuku	H 109	Fresh	1064	1220
9	Kahuku	H 109	Preserved	1066	1160
10	Waianae	H 109	Fresh	1020	1160
11	Waianae	H 109	Preserved	1014	1130
12	Waialua	H 109	Fresh	822	910
13	Waialua	H 109	Preserved	834	906
14	Waialua	H 109	Fresh	710	735
15	Waialua	H 109	Preserved	756	705

* Tops included.

The Effects of Oven Drying and Air Drying on the Available Nitrogen Content of Soils:

At the time a field crop of sugar cane is harvested the soil in the field, as a

rule, is quite low in its concentration of "available" or readily soluble nitrogen. Immediately thereafter, however, upon exposure of the bare field to sunlight (warmth) and moisture, bacterial action appears to be stimulated and the formation of available nitrogen occurs from insoluble organic sources in the soil.

As a companion determination to the progressive sugar cane leaf-punch nitrogen field survey, an appraisal of the status of available soil nitrogen, at any given moment, is highly desirable. It is common knowledge, however, that by the time representative soil collections can be made, dried and composited for analysis a delay of ten days or longer will have ensued and the available nitrogen concentration will have been markedly changed. Either one of these conditions defeats the purpose of the determination.

Therefore an attempt has been made (a) to ascertain the shift in soil nitrogen availability as brought about by various methods of artificial and natural drying of the soil specimen, and (b) to develop a rapid method of measuring soil nitrogen availability with fair accuracy in the shortest possible space of time immediately following the sampling of the field soil.

As a general rule, soils intended for analysis are air dried before they are disintegrated, sieved, mixed and prepared for the analyst. Soils taken from the field may vary from saturation with moisture to a wetness below the wilting coefficient. On some plantations, or in localities of high humidity, air drying of some soils may require days or even weeks. Hence, if drying is an analytical prerequisite, rapidity of drying is a necessity unless other methods of making the determination be found.

Obvious methods of drying soil are to place the sample in an oven at controlled temperature or near sources of warmth in the sugar factory. We shall consider the extent of the changes, if any, that take place in the ammoniacal, nitrate and *total available* nitrogen content of soils when they are dried by various means and for different periods of time.

Experimental: Temperatures were determined at which it was found possible to dry soils in a short time, say, between an hour and twenty-four hours. Analyses of the samples were made immediately after drying by means of the rapid chemical methods. This procedure would indicate any increases of available nitrogen which may have developed due to heating, and also it should show the extent of such changes brought about by the heating.

Preliminary tests with soils Nos. 27 and 91 indicate that at 105° C. these samples were sufficiently dry to be workable in about one hour. At 60° C., twenty-four hours or longer were necessary to secure comparable drying. These two temperatures were therefore selected to produce what may be considered good indications of the changes which may take place in the available nitrogen of soils when so treated. For this purpose a representative number of soils were selected which are known to be difficult to dry.

In order to study the effect of prolonged heating at these temperatures, other portions were dried at intervals in the oven, some for as long as two continuous weeks. Comparative figures were also obtained on air-dried and wet portions of these soils. The air drying was carried out in the shade at room temperature. The method used to sample the wet soil is set forth in the appended procedure. The analytical data are discussed separately under (a) ammoniacal, (b) nitrate and (c) the sum of the two, or total available nitrogen.

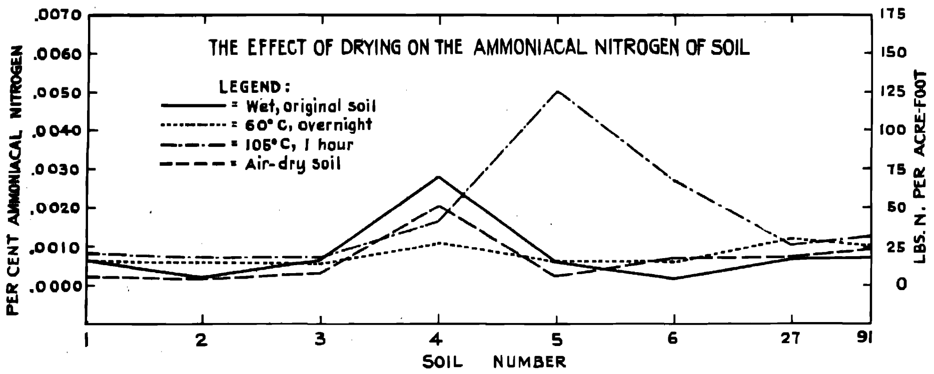


Fig. 3

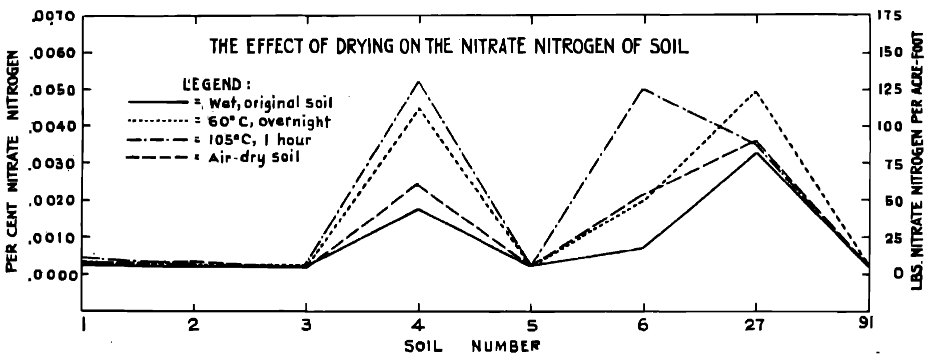


Fig. 4

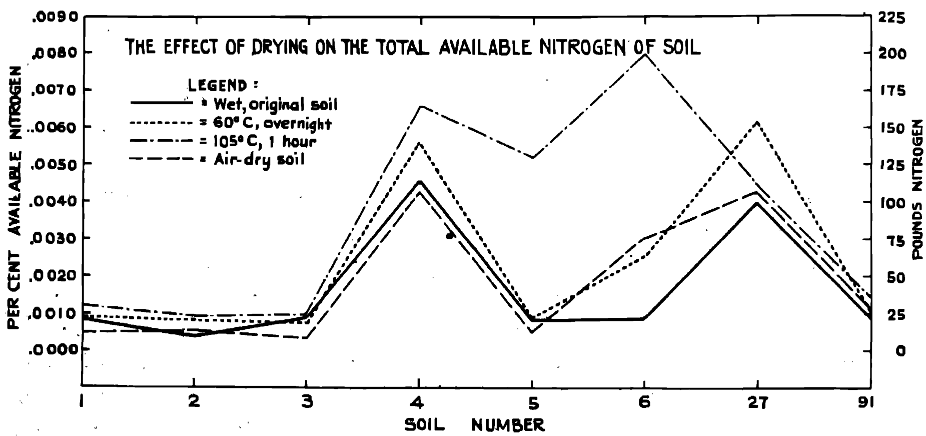


Fig. 5

Ammoniacal Nitrogen: Comparisons of the ammoniacal nitrogen content of the soils studied show that the air-dried portions are, in most cases, slightly lower in ammonia nitrogen than the moist, original specimens (Fig. 3 and Table IV). The changes found were less than 25 pounds per acre-foot in the eight soils studied. Minor differences were also noted when the soils were heated overnight in an oven below 60° C. These soils were not completely or sufficiently dried. One sample, No. 4, decreased by 40 pounds ammonia nitrogen per acre-foot compared with the wet soil, but this ammonia was apparently nitrified and not lost, for the nitrate nitrogen increased by the same amount. When the drying period was advanced to 40 hours, there were small gains observed generally. However, samples kept in the oven at 60° C. for two weeks increased tremendously in ammonia nitrogen in every case. The gains ranged from 65 pounds to 300 pounds nitrogen per acre-foot.

On drying for one hour at 105° C., the changes in the ammoniacal nitrogen content varied from a 30-pound decrease to an increase of over 100 pounds (soil No. 5). The decrease in one soil (No. 4) is traceable to nitrification which also occurred at 60° C. However, when the soils were left in an oven over a weekend (about 65 hours) at the higher temperature, significant increases of 50 pounds to over 200 pounds nitrogen per acre-foot took place in every case. These figures show that an increase in temperature and also in the period of heating markedly step up the concentration of ammoniacal nitrogen in these soils. Below 60° C., where it is necessary to dry for twenty-four hours or longer, slight to over 25-pound increases of ammonia nitrogen were found. At the higher temperature of 105° C. for one hour, very great changes may thus be expected in some soils. For this reason temperatures as high as 105° C. can not be used to dry soils for the determination of field availability in ammoniacal nitrogen. Extended heating at elevated temperatures is especially to be avoided, even temperatures as low as 50° C. to 60° C. Under these conditions the factors favoring ammonification are intensified and predominate and large increases of ammonia generally prevail. Such conditions, of course, do not exist in the fields.

Nitrate Nitrogen: The nitrate form of nitrogen is generally not affected much by temperature changes or by extended heating. In the two soils, Nos. 4 and 6 (Table V and Fig. 4), in which large increases of nitrate nitrogen do occur upon heating, it may be explained, perhaps, as due to the acceleration of the natural processes of nitrification. By the subsequent reanalyses of all samples, the wet soils were found to have increased in nitrate nitrogen to the high levels reached by the samples dried by the various methods described. In soil No. 4, the gain is apparently due to nitrification of the ammoniacal nitrogen originally present in the wet soil and in No. 6, to nitrification of organic matter.

Nitrification appears to be accelerated in the early stages of heating and ammonification in the later stages.

Total Available Nitrogen: Total available nitrogen, i.e., the sum of the ammoniacal and nitrate forms, in naturally wet soils appeared to change only slightly, if any. Exceptions were found, however. In one wet soil, No. 6 (Table VI and Fig. 5), the total available nitrogen increased by about 50 pounds per acre-foot when the soil was air dried. This gain is due to an increase of both the ammoniacal

TABLE IV

PER CENT AMMONIACAL NITROGEN

Lab. No.	Description of samples	Specimens analyzed	Treatments: Air-dry soil	Wet orig. fld. soil	Below 60° C.: Over-night	40 hrs.	2 wks.	105° C.: 1 hr.	60 hrs.
1	Honolulu Plantation Co., near poi factory	Immediately after treatment	.0002	.0006	.0006	.0007	.0050	.0008	.0028
		After 2 weeks	.0002	.0002	.0002	.0006	.....	.0006	.....
2	Expt. Stn. Seedling Station, Ewa	Immediately after treatment	.0002	.0002	.0006	.0009	.0028	.0007	.0026
		After 2 weeks	.0002	.0002	.0003	.0007	.....	.0006	.....
3	Waialua Agric. Co., Ltd., Mokuleia side	Immediately after treatment	.0002	.0007	.0006	.0008	.0056	.0007	.0028
		After 2 weeks	.0004	.0002	.0006	.0006	.....	.0007	.....
4	Waialua Agric. Co., Ltd. valley soil	Immediately after treatment	.0019	.0028	.0011	.0020	.0150	.0016	+.0100
		After 2 weeks	.0021	.0002	.0011	.0018	.....	.0018	.....
5	Kahuku Plantation Co., Waialua side	Immediately after treatment	.0003	.0006	.0006	.0007	.0005	+.0050	.0030
		After 2 weeks	.0002	.0002	.0003	.0006	.....	.0050	.....
6	Kahuku Plantation Co., Punaluu	Immediately after treatment	.0008	.0002	.0006	.0012	+.0100	.0030	+.0050
		After 2 weeks	.0006	.0002	.0003	.0010	.....	.0024	.....
27	Olaa Sugar Co., Ltd., Field 4–5	Immediately after treatment	.0007	.0007	.0012	.....	.....	.0010	+.0050
		After 2 weeks	.0012	.....	.0011	.....	.....	.0010	.0040*
91	Manoa Substation, surface, Mauka of D–3	Immediately after treatment	.0009	.0007	.0010	.....	.....	.0012	+.0100
		After 2 weeks	.....	.....	.0008	.....	.....	.0011	.....

* Dried on hot plate for 10 hours.

Plus sign (+) denotes quantity more than that indicated.

TABLE V

PER CENT NITRATE NITROGEN

Lab. No.	Description of samples	Specimens analyzed	Treatments: Air-dry soil	Wet orig. fld. soil	Below 60° C.: Over-night	40 hrs.	2 wks.	105° C.: 1 hr.	60 hrs.
1	Honolulu Plantation Co.,	Immediately after treatment	.0003	.0002	.0003	.0005	.0003	.0004	.0002
	near poi factory	After 2 weeks	.....	.0005	.0002	.0002	.....	.0002	.0002
2	Expt. Stn. Seedling	Immediately after treatment	.0003	.0002	.0002	.0002	.0002	.0002	.0002
	Station, Ewa	After 2 weeks	.....	.0005	.0002	.0002	.....	.0002	.0002
3	Waialua Agric. Co., Ltd.,	Immediately after treatment	.0002	.0002	.0002	.0002	.0003	.0003	.0002
	Mokuleia side	After 2 weeks	.....	.0003	.0002	.0002	.....	.0002	.0002
4	Waialua Agric. Co., Ltd.	Immediately after treatment	.0024	.0018	.0045	.0040	.0020	+.0050	.0028
	valley soil	After 2 weeks	.....	.0050	.0040	.0045	.....	.0040	.0028
5	Kahuku Plantation Co.,	Immediately after treatment	.0002	.0002	.0003	.0003	.0003	.0003	.0002
	Waialua side	After 2 weeks	.....	.0002	.0002	.0002	.....	.0003	.0002
6	Kahuku Plantation Co.,	Immediately after treatment	.0022	.0007	.0017	.0035	.0030	+.0050	.0030
	Punaluu	After 2 weeks	.....	.0022	.0020	.0031	.....	.....	.0030
27	Olaa Sugar Co., Ltd.,	Immediately after treatment	.0036	.0033	.0050	.....	.....	.0035	.0038
	Field 4–5	After 2 weeks	.....	.....	.0045	.....	.....	.0033	.0025*
91	Manoa Substation, surface,	Immediately after treatment	.0002	.0002	.0002	.....	.....	.0002	.....
	Mauka of D–3	After 2 weeks	.....	.....	.0002	.....	.....	.0002	.0002

* Dried on hot plate for 10 hours.

Plus sign (+) denotes quantity more than that indicated.

TABLE VI

PER CENT TOTAL AVAILABLE NITROGEN

			Treatments						
					Below 60° C.			105° C.	
Lab. No.	Description of samples	Specimens analyzed	Air-dry soil	Wet orig. fld. soil	Over-night	40 hrs.	2 wks.	1 hr.	60 hrs.
1	Honolulu Plantation Co., near poi factory	Immediately after treatment	.0005	.0008	.0009	.0012	.0053	.0012	.0030
		After 2 weeks	.0005	.0007	.0004	.0008	.....	.0008	.0026
		Water added after heating	.....	.0008	.....	.0027	.....	.0042	.0072
2	Expt. Stn. Seedling Station, Ewa	Immediately after treatment	.0005	.0004	.0008	.0011	.0030	.0009	.0028
		After 2 weeks	.0004	.0007	.0005	.0009	.....	.0008	.0023
		Water added after heating	.....	.0010	.....	.0028	.....	.0042	.0102
3	Waialua Agric. Co., Ltd., Mokuleia side	Immediately after treatment	.0004	.0009	.0008	.0010	.0059	.0010	.0030
		After 2 weeks	.0006	.0005	.0008	.0008	.....	.0009	.0024
		Water added after heating	.....	.0022	.....	.0042	.....	.0062	.0102
4	Waialua Agric. Co., Ltd. valley soil	Immediately after treatment	.0043	.0046	.0056	.0060	+.0170	+.0066	+.0130
		After 2 weeks	.0044	.0052	.0051	.0063	.....	.0058	+.0130
		Water added after heating	.....	.0052	.....	.0105	.....	.0105	.0122
5	Kahuku Plantation Co., Waialua side	Immediately after treatment	.0005	.0008	.0009	.0010	.0053	+.0053	.0032
		After 2 weeks	.0004	.0004	.0005	.0008	.....	.0053	.0028
		Water added after heating	.....	.0015	.....	.0040	.....	.0108	.0082
6	Kahuku Plantation Co., Punaluu	Immediately after treatment	.0030	.0009	.0025	.0047	+.0130	+.0080	+.0080
		After 2 weeks	.0024	.0024	.0023	.0041	.....	.....	.0064
		Water added after heating	.....	.0016	.....	.0058	.....	.0085	.0082
27	Olaa Sugar Co., Ltd., Field 4–5	Immediately after treatment	.0043	.0040	.0062	.....	.....	.0045	.0086
		After 2 weeks	.0052	.....	.0056	.....	.....	.0043	.0065
91	Manoa Substation, surface, Field 7	Immediately after treatment	.0011	.0009	.0012	.....	.....	.0014	+.0100
		After 2 weeks	.....	.....	.0010	.....	.....	.0013	+.0100

Plus sign (+) denotes quantity greater than that indicated.

and nitrate forms. After standing for two weeks, this particular soil gained as much as 40 pounds nitrate nitrogen. It is further observed that this soil kept in a moist condition for a period of time increased to the same nitrogen content as the air-dried portion when both were reanalyzed later. The conclusion which may be safely drawn, we believe, is that the analysis of a soil for available nitrogen in naturally wet specimens taken from the field is quite possible and gives reasonably true and accurate results. Where an apparent exception is found, as was the case in soil No. 6, it may be due to an actual change taking place during the time required to air dry the soil.

When dried overnight in an oven at 60° C., or lower, gains up to 50 pounds nitrogen per acre-foot were found. When the soils were left over a weekend in the oven at this temperature, increases ranged up to 100 pounds nitrogen per acre-foot. Samples kept for two weeks at 60° C. gained from 65 pounds available nitrogen to over 300 pounds. At a temperature of 105° C. for one hour, these soils gained from 3 pounds to over 175 pounds nitrogen and increased from 55 pounds to over 225 pounds when incubated (dried) over a weekend at 105° C.

Drying in the oven either at 60° C. or at 105° C. increases the available nitrogen content of these soils. The increases, which take place in a sizable proportion of the samples dried at 60° C. and for a short period, occur in every soil tested when dried for longer periods or at higher temperatures.

Discussion: The experimental figures, although obtained from a limited number of soils which were nevertheless a representative selection, definitely support the belief that analyses of wet field samples of soils give a truer picture of the available nitrogen supply in the field at the time of sampling than either air-dried or oven-dried portions of the same soils. This brief study was not intended to learn the causes governing the relationships found to exist between nitrogen values and various methods of soil drying, but there are sufficient data presented to point toward accelerated bacterial activity and also chemical decomposition due to the elevated temperatures employed as major causes of the increases in available nitrogen noted in the dried portions of the soils. Soils which were dried, either oven or air dried, when left standing in the dry state for a week to ten days did not change in available nitrogen as compared with their respective contents immediately after drying. (Refer to the lower figures in Tables IV, V and VI.) However, when the dried soils were kept moistened with distilled water for a week, the portions dried at 105° C. and also those dried at 60° C. for periods longer than 40 hours showed tremendous increases of available nitrogen. Although no attempt was made to keep the soils uncontaminated, those kept at 105° C. for 60 hours are apparently only partially sterilized. On the addition of moisture, the bacteria which produce ammonia increased to the greatest extent in the soils kept at the highest temperature and for the longer period. This is shown (Table IV, upper figures) in the ammonia content of the soils. The organisms detrimental to the nitrifying bacteria were not affected or destroyed when heated below 60° C. overnight.

The soils selected for this test included those extremely difficult to dry. The wet sampling method proposed is admittedly difficult to employ on these soils, but when these same soils were dried, by whichever means selected, the subsequent handling of the dry specimens was much more difficult and consumed more time

than the method suggested. This is due to the fact that the soils in question caked into a solid, rocky mass when dried.

The laboratory sampling method used, and which is recommended for handling moist or wet field soils, is as follows:

1. If the sample taken from the field is large, spread the soil out on a wide sheet of heavy paper.
2. Break up the large masses into smaller pieces with a trowel.
3. Start from one end of the sheet and quarter by spading off a quarter of each large mass of soil and also taking one-fourth of the smaller pieces.
4. Break up the sample further and repeat Step 3 until one or two pounds are obtained.
5. Spread the sample on a square, 8-mesh wire screen (8 mesh to a linear inch) about 18 inches to a side. Press the soil with a large wooden mallet. (The screen should be made so that the wire bottom rests about three inches above the table, the screen height being about two inches or more.)
6. Press a portion of *each* part of the sample through the screen until about a tumblerful is obtained. (It is not necessary to press all of the soil through the screen.)
7. Mix by means of a spatula.
8. Fill the 10-gram soil cup by taking a small portion of soil from various parts of the mound, pack the cup solidly and level it.
9. Remove excess soil from spatula and cup.
10. Transfer the contents of the cup to a 250-ml. beaker by digging out neatly with the cleaned spatula.
11. Add 50 ml. of Reagent 5, N and stir well, using two stirring rods held together in one hand if necessary.
12. Filter through a dry filter into a 100-ml. beaker and proceed with the usual R.C.M. ammoniacal and nitrate nitrogen determinations on the filtrate.

Since the soil cup is packed solidly, the regular R.C.M. tables giving ammoniacal and nitrate nitrogen values may be used, and correctly so, without further change.

The wire screen is washed and brushed and the excess water shaken off. It is then ready for use again without further drying.

Literature Cited

(1) Hance, Francis E., 1936. Soil and plant material analyses by rapid chemical methods. The Hawaiian Planters' Record, 40: 189–299. (Agric. and Chem. Series Bulletin No. 50.)

(2) ———, 1937. Soil and plant material analyses by rapid chemical methods—II. The Hawaiian Planters' Record, 41: 135–186. (Agric. and Chem. Series Bulletin No. 51.)

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
JUNE 20, 1941, TO SEPTEMBER 3, 1941

Date	Per pound	Per ton	Remarks
June 20, 1941	3.525¢	$70.50	Puerto Ricos, 3.50; Philippines, 3.55.
July 3	3.45	69.00	St. Croix; Puerto Ricos.
" 18	3.47	69.40	Puerto Ricos, 3.46, 3.47, 3.48.
" 21	3.45	69.00	Puerto Ricos.
" 23	3.5267	70.53	Puerto Ricos, 3.51, 3.52, 3.55.
" 24	3.55	71.00	Puerto Ricos.
" 28	3.58	71.60	Puerto Ricos, 3.57, 3.59.
" 29	3.60	72.00	Puerto Ricos.
" 30	3.625	72.50	Puerto Ricos, 3.60, 3.65.
Aug. 1	3.65	73.00	Puerto Ricos.
" 6	3.715	74.30	Puerto Ricos, 3.70, 3.73; Cubas, 3.73; Philippines, 3.73.
" 7	3.75	75.00	Cubas.
" 11	3.80	76.00	Puerto Ricos.
Sept. 3	3.50	70.00	Puerto Ricos.

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